BOILER PLANT TESTING

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A CRITICISM OF THE PRESENT BOILER TESTING CODES AND SUGGESTIONS FOR AN IMPROVED INTERNATIONAL CODE

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INTRODUCTION.

THERE is at present no practical and definite Code in Great Britain for boiler plant testing, and, consequently, such tests are largely carried out according to the fancy of the particular engineers engaged. I am decidedly of the opinion that the time has arrived for the adoption of a standard up-to-date Code devised on thoroughly practical lines, especially in view of the urgent necessity of fuel economy, and the fact that nearly 50 per cent. of the coal consumption of Great Britain is used for the one operation of steam generation.

What is supposed to be the Standard Code in Great Britain is that of the Institution of Civil Engineers ("Report of the Committee on Tabulating the Results of Steam Engine and Boiler Trials". Revised 1913. Published by Messrs. William Clowes & Sons Ltd., 94 Jermyn Street, London, S.W. 1. Price 3/- net).

The original Committee of the Institution of Civil Engineers for this purpose was appointed on the 29th June, 1897, and they made an Interim Report on the 25th April, 1901, followed by a final Report on the 14th April, 1902. The Committee was then reappointed on the 19th October, 1909, to revise the original Code of 1902, and the Report of this latter Committee is embodied in the present (1913) Code. In practice, however, this Code is ignored because it is too complicated and unpractical.

I am of the opinion also that the Code is entirely out-of-

date, and, with all due respect to the Institution of Civil Engineers, the devising of an Improved Code is essentially the business of two branches of engineering, chemical and mechanical.

The Standard Code in America for Boiler Plant Testing is the "Rules for Conducting Performance Tests of Power Plant Apparatus, Code 1915," of the American Society of Mechanical Engineers, 29 West Thirty-ninth Street, New York, U.S.A., being the Report of the Power Test Committee, which resulted from the Council's resolution of 13th April, 1909. As is of course well known, this Code is at present under revision by the "Power Individual Committee, No. 4" (Messrs. E. R. Fish (Chairman), D. D. Pratt (Secretary), A. D. Bailey, W. N. Best, A. A. Carey, and E. B. Ricketts), and by the courtesy of the Secretary I have been able to study the preliminary draft of the Report of this Committee, so that any criticisms and remarks of mine in this book apply to the Final Revised Code. I think that this American Code, even as revised by the "Power Individual Committee, No. 4," is still open to criticism, although much superior to the British Civil Engineers' Code.

I suggest, therefore, that the time is ripe for the devising of a Standard International Boiler Testing Code by the American, British and French Engineering and Scientific Societies working in collaboration.

In Great Britain the premier societies concerned are the Institution of Mechanical Engineers and the Institution of Chemical Engineers, with various other societies like the Civil Engineers, Electrical Engineers, Mining Engineers, and the Society of Chemical Industry, holding a watching brief. In America the lead would presumably be taken by the American Society of Mechanical Engineers, and in France by the Ingénieurs Civils de France.

The present book is a contribution towards the work of devising such an improved International Code, and I have divided it into the following parts:—

Part I.—"The Results at present being obtained on Boiler Plants in General," to show the necessity of adopting modern scientific methods in steam generation, and of devising a practical international test Code to encourage such work.

Part II.—"Criticisms of Existing Codes and Suggestions for Improvement." This part is divided under the following heads:—

1. The necessity of a separate Code for boiler plant testing.
2. The object of boiler plant testing.
3. Duration of test.
4. Sampling and analysis of the fuel.
5. Flue gas analysis.
6. The method of measuring the boiler feed-water.
7. Moisture in the steam.
8. Specific heat of superheated steam.
9. Steam or power used auxiliary to the production of steam.
10. Lbs. of water from and at 212° F. per 1,000,000 B.Th.U.
11. Various minor points.
12. The method of calculating the results.

All these points are matters that could be settled immediately by American, British and French Committees appointed to devise the International Code, and would include the provision of a list of "recommended" instruments, calorimeters, water meters, combustion recorders, pyrometers, etc.

Part III.—"Suggestions for New Features that may be added in the future to an International Code as the result of further discussion and investigation." This chapter includes

the following heads, and consists of various matters which may, or may not, be added to an International Code:—

1. The question of the use of a special factor depending on the quality of the fuel.

2. Labour, attendance, repairs, upkeep, interest, and depreciation.

3. Dust and grit in the chimney gases.

4. Steam meters.

Part IV.—"Design of a New and Improved Code as a suggested basis for the International Code," giving, as an example, the results of an actual boiler test according to the suggested Code.

For convenience and simplicity, throughout this book, the fuel under discussion is coal; but the same reasoning and principles will apply to all fuels, solid, liquid, and gaseous.

The general grounds for criticism of the Institution of Civil Engineers' Code, in particular, I consider to be as follows:—

1. The Code is far too academic and not adapted to practical requirements, and it appears to be drawn up with the idea that boiler tests are a luxury only to be carried out on rare occasions. Thus it takes up pages arguing about heat balance sheets, specific heat of flue gases, and the full chemical analysis of the fuel, and almost ignores matters of vital practical importance, such as the amount of auxiliary steam or power used on the plant, the price of the fuel, and the cost of evaporation of a unit of water.

2. The Code is completely out-of-date in the methods given for carrying out the test. For example, it insists on weighing or measuring the water in tanks, even at sea, and practically omits to mention the twenty different water meters available, and also does not discuss steam meters. Although it insists

rightly on a bomb calorimeter for fuel analysis, it recommends an instrument no one in this country, except the "Civils" Committee, has ever heard of, and as regards flue gas analysis, hand methods of the most antiquated and unpractical types are insisted upon. Automatic CO_2 Recorders, a commonplace of modern boiler plant work, are disparaged, but if used, an instrument is recommended which is many years out-of-date.

3. The Code is expressed in such a confused and complicated manner that it rivals the Income Tax and can only be understood with great difficulty, whilst the methods of calculating the results are so intricate as to be largely unintelligible without a great effort, even to specialists on the subject. Thus it is not drawn up in any logical sequence. The first sheet deals with "General Description of the Boiler," and then the second sheet follows with data from the test. We then come to "General Description of the Economiser and Superheater," and in this way general descriptive matter, data, and calculations are all mixed up together in the most extraordinary manner. The attempt also to regard the boiler, economiser and superheater as entirely separate is most confusing.

I have to confess that, if only because of the continual cross references, I have been compelled to buy a number of copies of the Code and cut them up with scissors, so that all the references to each point could be stuck on one large sheet of paper, and in this way to dissect the Code into a large number of separate sheets, so as to read it easily. For example, the question of auxiliary steam or power has five different references, and the particulars relating to the calculations based on the full chemical analyses of the fuel and the flue-gases are hopelessly involved. The American Mechanicals Code is infinitely superior in this respect, and is provided with an admirable index.

In studying the Civils Code at great length, one is com-

pelled to come to the conclusion first, that it applies only, more or less, to the years 1897-1901, the time of its original formation—and little alteration seems to have been made in 1913, so that it is about twenty years out-of-date—and secondly, that the Committee apparently have had in mind only academic tests on small boiler plants of one boiler or so. The attempts to apply the Code to moderate sized boiler plants, and especially to very large plants, like twenty "Lancashire" boilers or equivalent, prove it to be ludicrously unpractical, as I hope to show.

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2 Austin Friars,
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March, 1922.

CONTENTS.

PART I.

THE RESULTS AT PRESENT BEING OBTAINED ON BOILER PLANTS IN GENERAL.

THE new Code suggested in this book as a basis for an International Code is the result of fifteen years' continuous experience of boiler plant testing, comprising several thousand tests, during which time the methods of testing, and calculation, used have been gradually altered and improved until the Code has arrived at its present form.

There has not hitherto been much reliable information available as to the actual results being obtained in practice from week to week on the boiler plants of Great Britain. Much of the data obviously only applies to special test conditions, where everything is particularly favourable, especially as regards attention, quality of fuel used, rate of evaporation, repair of brickwork, etc., for obtaining the best results, and such data gives an entirely false impression as to the real figures that are being obtained in practice.

Thus Donkin, in his book "Heat Efficiency of Steam Boilers," gives fifty tables containing the results of 425 experiments on different boilers. These results are summarised on page 2 (being for the boilers only, without economisers).

The figures are, in my opinion, very much too high for average working conditions. It will be noted that they apply to boilers only, without economisers and superheaters, and we have extraordinary results like 72 per cent. efficiency for ten experiments on a "Lancashire" boiler only, whereas 107 experiments on a "Lancashire" boiler showed 62·4 per

cent., which is still a very high figure, and such as could only be obtained with the best attention. These figures, however, show the great variation being obtained, and in 107 "Lancashire" boiler tests, for example, we have figures from 42·1 to 79·5 per cent. efficiency.

Type of Boiler.	No. of Experiments.	Average Efficiency.	Average of Two Best Results.	Worst Result.
		Per Cent.	Per Cent.	Per Cent.
Water-tube, 1½-in. tube	6	77·4	84·1	66·6
Locomotive	37	72·5	83·3	53·7
Lancashire	10	72·0	74·4	65·6
Two-storey	9	70·3	76·1	57·6
"	29	69·2	79·8	55·9
Dry back	24	69·2	75·7	64·7
Return tube	11	68·7	81·2	56·6
Cornish	25	68·0	81·7	53·0
"	9	67·0	81·0	55·0
Wet back	6	66·0	69·5	62·0
Elephant	7	65·3	70·8	58·9
Water-tube, 4-in. tubes	49	64·9	77·5	50·0
Lancashire	40	64·2	73·0	51·9
Cornish	3	62·7	65·9	60·0
Lancashire	107	62·4	79·5	42·1
Dry back	6	61·0	73·4	54·8
Lancashire, 3-flue	6	59·4	66·7	52·0
Elephant	8	58·5	65·5	54·9
Lancashire	8	57·3	74·3	45·9
Vertical	5	56·2	76·5	44·2

W. S. Hutton, in his book, "Steam Boiler Construction" (1916), gives data for the performance of various types of boilers "which may generally be obtained in practice with boilers having tolerably clean heating surfaces, when fired with good coal," as follows:—

Type of Boiler.	No. of Tests Given.	Evaporation. Pounds of Water from and at 212° F.
Lancashire	24	8·25 to 12·02
Cornish	7	7·75 " 11·56
Egg-ended	6	6·52 " 8·56
Vertical	15	5·57 " 10·21
Water-tube	73	7·02 " 13·40

Again, some figures supplied by Molesworth :—

Description of Boiler.	Pounds Water from and at 212° F. Evaporated Per Lb. Average Coal.
Egg-ended	8·0
Cornish	8·0
Lancashire	9·0
Water-tube	8·0
Ordinary Marine	9·5
Tubular	9·5
Locomotive	10·5
Torpedo boat	13·0

André states that 1 lb. of the coals mentioned will evaporate, under ordinary practical conditions, the following amounts of water :—

Quality of Coal.	Evaporation. Pounds of Water from and at 212° F.
Gaseous coals	6·25
Bituminous-fuliginous	8·00
Flaming	8·75
Clear burning	9·25
Semi-bituminous	9·10
Anthracite	9·20

A particularly ludicrous statement, in a recent (1920) "Chemical Pocket Book," is as follows :—

"The efficiency of a boiler should be as near to 80 per cent. as possible, this figure being considered excellent. A more usual figure is 70 per cent. which is quite good. The water from and at 212° F. per lb. of combustible is a good indication of the efficiency of a boiler, and under normal conditions should be about 12·0 lbs."

In general, and quite apart from academic absurdities, it is not realised how bad are the figures for the average boiler plant. Thus, among practical engineers, it is usual to assume that 1 lb. of average coal evaporates 7 to 8 lbs. of water from and at 212° F., and, for example, most engine builders take a figure of 8·0 lbs. in calculating the steam

consumption of their engines and the size of boiler plant necessary. In my experience such figures are much too high. Some of the present authorities are also of this opinion, and, for example, the figures given in Kempe ("Engineers' Year Book, 1920") are as below :—

Description of Boiler.	Efficiency, Per Cent.
Small cylindrical boiler (no economisers)	45 to 55
Large cylindrical boiler with economiser	60 ,, 70
Small water-tube ,, ,, ,, ...	50 ,, 60
Large ,, ,, ,, ,, ...	70
In very good condition	70 to 75
Locomotive boiler, moderately fired	65 ,, 70
Marine boiler, well fired	60 ,, 70

Most of the exaggerated opinions as to the figures for the performance of steam boiler plant seem to be due to the fact that it is not realised how important is the quality of the fuel. The performance figures of any boiler plant depend largely on this point. Thus, as I will discuss in detail later, if a coal of 12,000 B.Th.U. deteriorates, say 10 per cent., to 10,800 B Th.U., the loss in evaporation in practice is much more than 10 per cent. The difficulties caused by the accumulation of ash, and the reduction of radiant heat causes a much greater drop in evaporation than that corresponding to the mere reduction in heating value, and the net reduction is, say, 15 per cent. to 17½ per cent. instead of 10 per cent.

In the same way, an increase in heating value of 10 per cent., say from 12,000 B.Th.U. to 13,200 B.Th.U., gives more than the mere 10 per cent. increase in heating value, because of the greater freedom from ash and the increased radiant heat. These facts must, therefore, be borne in mind in considering the figures given on the different types of plants.

For example, Bryan Donkin and A. B. W. Kennedy published, in 1897 ("Experiments on Steam Boilers," Offices of "Engineering"), the results of a series of experiments on the performance of a number of types of steam boilers, comprising twenty-one separate determinations, and including "Vertical," "Tubular," "Lancashire," "Locomotive," "Water-tube,"

"Cornish," "Cornish Multi-tubular" and "Elephant" boilers. These experiments, however, do not give us much data of practical value, because they were carried out under ideal conditions with coal of extraordinarily good quality, namely, the finest Welsh steam coal. Thus the heating value of the dried coal was no less than 15,560 B.Th.U. per pound, with only 3 per cent. ash, and the theoretical evaporation of 1 lb. of the dried coal from and at 212° F. was given as 16·1 lbs. of water. As typical of the figures obtained, a "Lancashire" boiler gave 70·4 per cent. efficiency without economisers, and 9·92 lbs. of water evaporation per pound of coal. A "Cornish" boiler showed 78·3 per cent. efficiency with 11·4 lbs. of water from and at 212° F. per pound of coal, whilst a "water-tube" boiler showed 74·4 per cent. efficiency and 9·90 lbs. of water per pound of coal.

These results obviously only apply to purely abnormal conditions, and are of little use in arriving at average figures for boiler plants as generally working in industry.

The firm with whom I am associated have been engaged continuously for the past dozen years or so in carrying out complete scientific investigations into the working of steam boiler plants in Great Britain, and also in reorganising existing plants or erecting new plants. From 1908 to the present time we have tested nearly 500 different boiler plants, with a total annual coal bill of about 4,000,000 tons, and made a personal examination (without testing) of about 2000 plants with a total coal bill of about 15,000,000 tons per annum.

I have at the present time the tabulated results of the complete scientific investigation of 400 different boiler plants, with a total coal bill of 3,250,000 tons per annum, the number of boilers being 1513, in forty-one different industries, as detailed on page 6.

Before discussing the results obtained, I should like to give a short account of the methods used in carrying out the tests, which were in each case of the most comprehensive character, and not a mere inspection and expression of opinion

in the sense used by certain Fuel Economy Associations or Organisations.

A detailed test of the plant was made first for one working day, and a further test for one week was carried out as a

Industry.	Number of Plants Tested.
Aniline dye manufacturers	4
Breweries	5
Calico printers	10
Carpet manufacturers	6
Cement ,,	1
Collieries (including several steel works)	112
Cotton bleaching	9
,, mills	23
,, piece dyeing	18
,, yarn ,,	9
Dyeing and cleaning	8
Electricity station	1
Engineering	10
Explosives	27
Fine organic chemicals	3
Flour mills	4
Food products	3
Glue manufacturers	8
Hat ,,	3
Heavy inorganic chemicals	7
Hosiery mills	5
,, dyeing	4
Hospitals	1
India-rubber manufacturers	5
Jute mills	1
Lace ,,	7
,, bleaching	3
Laundries	1
Linen mills	2
Paint manufacturers	1
Paper mills	41
Potteries	4
Pumping station	1
Residential mansions	1
Soap manufacturers	3
Silk dyeing and printing	2
Tanneries	7
Textile, special	1
Woollen mills	36
,, yarn dyeing	1
Total	406

check on the figures for the fuel used and the water evaporated, and to ascertain the weekly conditions, including all week-end losses due to stoppage of plant, etc.

It will be clearly understood that the object of these tests

was to find out the exact normal everyday working conditions of the plant, particularly as regards efficiency and the cost in coal for the production of a unit of steam (evaporation of 1000 gallons of water), so that a scheme of reorganisation could be devised for the more economical production of steam—that is to say—these figures represent the true performance of the plants as run from week to week, and the boiler-house staff worked the plant as usual.

In carrying out the tests, the water level in the boilers and the general condition of the fires was the same at the end as at the commencement of the test. With regard to the details of the carrying out of the tests we have:—

Weight of Fuel Used.—This was determined in the usual various ways, depending on the circumstances of the case, from weighing the fuel in barrows or bags, to weighing carts and railway trucks direct.

Analysis of Fuel.—As is well known, it is an extremely difficult matter to get a thoroughly average sample of coal, especially when there is variation in the quality, and we took the greatest care in this respect. Samples were taken every half-hour by the clock, and also every hour and placed in separate receptacles. At the end of the trial the accumulated hourly and half-hourly samples were broken up, thoroughly mixed, quartered, and so on, as usual, several pounds being finally taken in sealed tins for analysis. There were thus obtained two entirely independent samples of the same fuel. In the same way we took samples of coal every day during the long check test as a check on the figures for the day. The two days' samples were then analysed separately, and the average figures taken. If more than one quality of fuel was used on the test, each separate quality had two independent samples taken as above described, so that in some cases on a day's trial as many as six different samples were analysed and the results averaged.

As regards the analysis of the coal, the heating value was determined by means of an oxygen bomb calorimeter,

("Mahler-Donkin"). The bomb type of calorimeter is, of course, acknowledged to be the standard scientific instrument for accurate heat determination, and the method consisted in burning the damp fuel (as fired) in a platinum-lined gunmetal bomb in oxygen at about 450 lbs. pressure per sq. in. The ignition is made inside the bomb by means of a fine platinum wire heated by outside electric contact. If platinum wire was not obtainable, fine iron wire was used, and a correction made for the heat of combustion of the iron to iron oxide. The bomb is covered with a known amount of water at a known temperature, and after ignition the rise in temperature observed with a thermometer graduated to $\frac{1}{100}$° C. As the combustion is instantaneous and totally enclosed, the heating value is obtained direct without any corrections being required. Further, the combustion is always complete, which is not the case with many inferior types of calorimeter.

As I will discuss later in detail, there is much confusion with regard to the method of expressing the results. In a bomb calorimeter of this description the moisture in the coal, and the moisture formed by the combustion of the (organic) hydrogen in the coal, are driven off as steam and condensed again in the bomb, so that the whole of the heat is retained and included in the heating value. In actual practice, however, when the coal is thrown into the furnace, the water is driven off as steam and tends to escape, and to pass away in the chimney base at the same temperature as the gases, say, at an average of 400° F. Thus the gross heating value as obtained by the bomb is slightly higher than the real heating value that would be obtained in practice because of this loss of heat due to steam escaping in the gases. In view of these difficulties I have, in each case, taken the higher or gross heating value, that is, the heating value as actually obtained by the combustion of the damp coal in the bomb calorimeter.

With regard to the percentage of ash, this was determined by complete combustion in the muffle furnace, so that the

figures given for the amount of ash represent the real non-combustible matter, not allowing for any slight loss that might take place by the volatilisation of a portion of the ash. The percentage of ash obtained from the boiler plant will, of course, always in practice be slightly higher, as it is impossible to obtain complete combustion of the ashes, and under good average conditions there is always, say, 1 to 2 per cent. of combustible matter in the ash as thrown away on the ash dumps. I may say, however, that in scores of boiler plants, there is a big loss in this direction, and it is quite possible to find as much as 5 per cent., or even up to 10 per cent., of combustible matter still retained in the ash. I have actually come across several instances where one works has bought ashes from another works for road-making, etc., and then used these ashes as fuel under the boilers.

Water Evaporated.—Various methods were used, depending on circumstances, to measure the water evaporated, but generally the method adopted was the use of a well-known make of pressure type hot-water meter calibrated before each test, and working between the boiler feed pump and the economisers.

Moisture in Steam.—Another difficulty, which I will discuss in detail later, in boiler plant testing is the fact that non-superheated steam always contains a certain amount of moisture, varying from 0 to 5 per cent., apart from priming, that is water from the boiler plant which has not been converted to steam. Theoretically, therefore, the amount of moisture in the steam should be determined and this amount deducted (with suitable temperature allowances) from the evaporation in calculating the true performance of the boiler plant. The practical difficulties in the way of this are, however, very great, and on this account, most boiler tests are carried out without determining the moisture in the steam, and we have followed the general practice in this respect.

Analysis of Feed-Water.—Samples of the feed-water

were taken every half-hour during the day's test, and good average samples obtained in this way. The samples were analysed by the "Wanklyn" soap test method before and after boiling, giving the permanent and temporary hardness, although in exceptional cases the full scientific analysis of the feed-water was carried out in the usual lines to determine the parts per 100,000 of calcium and magnesium bicarbonate and sulphate, including the total solids, etc. I may say that in my experience the soap test is a very convenient method, although somewhat despised by most chemists.

Temperature of Feed-Water.—On the day's test, the temperature of the feed-water, before and after the economisers, was taken every half-hour, or oftener if the variation was considerable. For this purpose we generally used calibrated mercurial thermometers, as the ordinary economiser thermometers supplied with economisers are not very accurate after months of work.

Draught Measurement.—On the day's test the draught was taken every half-hour, in various convenient positions on the boiler plant, such as the side flues of "Lancashire" boilers, the main flues, chimney base, before and after the economisers, and other similar positions. A ½-in. wrought-iron pipe was inserted into the middle of the flues in each case, and the draught taken with an ordinary draught gauge of the glass "U" tube type.

Temperature of the Flue Gases.—For this determination a well-known make of pyrometer was used, of the thermo-electric type, with platinum-iridium and platinum junction, in a porcelain tube enclosed in a steel tube, and connected through standardised coils of wire to a voltmeter graduated direct from 212° to 1500° F. The instrument was arranged with a two-way switch, two coils of wire, and pyrometers in the flue before and after the economiser, so that the two readings could be taken practically simultaneously. Before each test the instruments were calibrated by determining the boiling-point of some substance of high boiling-point, such as

aniline, using for the purpose a special form of iron condenser. As usual, on the day test the readings were taken every half-hour.

Percentage of CO_2 in Flue Gases.—In each case some reputable make of Combustion Recorder was fitted on the plant, and the percentage of CO_2 recorded at the rate of about 20 analyses per hour on a chart, along with the time of the analysis. One week's run was taken in this way in each case. Samples of the gas were taken from the side flues or the downtake of each boiler in rotation, allowing as a rule about twelve hours (say 240 analyses) on each boiler, so that at the end of a week a very good average was obtained. We also in many cases fitted up an apparatus for taking a large volume of the flue gases, say 15 to 20,000 c.c., very slowly during the whole day's test, so that at the end of the trial this 15 to 20,000 c.c. represented fairly the average during the day. The apparatus was then taken to our laboratories and the contained gas analysed by means of the "Orsat" apparatus to determine the percentage of CO (carbon monoxide) after the CO_2 and the oxygen had been absorbed in the usual way.

Steam Pressure.—On the day's test the steam pressure was taken every half-hour, or oftener if there was a consider-fluctuation.

Temperature of Superheated Steam.—On the day's test the temperature of the superheated steam was taken every half-hour with a calibrated mercurial thermometer, as, like economiser thermometers, the thermometers in continuous use with superheaters are seldom very accurate.

Auxiliary Steam.—With regard to the steam or power used as auxiliary to the production of steam, in the case of an engine, the indicated horse-power of the engine was taken, and from the type of engine in use a very good idea was obtained of the amount of steam used. Thus, for the ordinary enclosed, forced-lubrication, high-speed engine for driving forced or induced draught fans, an average figure is 35 lbs. of steam per indicated horse-power. In the case of a motor drive the

power used is, of course, very easily determined by measuring the amps. and the volts. The real difficulty is in connection with the amount of steam used in the form of steam jets either under or over fire-bars, and for this we used the special apparatus described later (p. 107).

Unfortunately, I cannot give the detailed figures for the performance of each of the 400 plants, since the amount of space occupied by such a mass of figures would be outside the limits of this book.

In the first place, however, *the true average net working efficiency of the whole of the* 400 *tests is* 58 *per cent.*, and I feel sure that these can be taken as thoroughly representative of the boiler plants of Great Britain, since, in addition to this large numbers of tests carried out in many different industries, the 2000 plants we have inspected, representing, as already stated, a coal bill of 15,000,000 tons per annum, were all found to be working on the same general lines.

The figures can be divided as follows, the highest individual plant being 82·21 per cent. and the lowest 32·50 per cent:—

Net Working Efficiency. (Boilers, Economisers and Superheaters.)	No. of Plants.
1. 80 per cent. and over	2
2. 75 ,, ,, ,, ,,	9
3. 70 ,, ,, ,, ,,	17
4. 65 ,, ,, ,, ,,	58
5. 60 ,, ,, ,, ,,	69
6. 55 ,, ,, ,, ,,	96
7. 50 ,, ,, ,, ,,	80
8. Below 50 per cent.	69
Total	400

I gave ("Coal Saving by the Scientific Control of Steam Boiler Plants," "Engineering," 12th and 19th July, 1918) the true average figures for 250 of these plants (1000 boilers and 2,166,000 tons of coal per annum) as follows:—

AVERAGE OF 250 TYPICAL BOILER PLANTS.

A. *Working Day's Test* :—

Type of boiler	"Lancashire"
Number of boilers	4
Grate area	152·6 sq. ft.
Duration of test	9·43 hours
Amount of fuel used	30,131·72 lbs.
Analysis of fuel used :—	
British thermal units	11,822
Ash	11·5 per cent.
Fuel burnt per boiler per hour	798·8 lbs.
,, ,, ,, square foot of grate area per hour	20·9 ,,
Water evaporated	197,776 lbs.
,, ,, per boiler per hour	5243 ,,
,, ,, ,, square foot grate area per hour	137·4 lbs.
,, ,, ,, lb. fuel	6·56 ,,
Equivalent evaporation from and at 212° F. per lb. fuel	7·46 lbs.
Equivalent evaporation from and at 212° F. per 1,000,000 British Thermal Units	631·0 lbs.
Temperature of feed-water before economiser	116° F.
,, ,, ,, after ,,	193° ,,
Percentage of fuel bill saved by ,,	7·1 per cent.
Draught in side flue	0·40 in. W.G.
,, ,, main flue at exit of economisers or chimney base	0·80 ,, ,,
Temperature of flue gases before economisers	598° F.
,, ,, ,, ,, after ,,	478° ,,
Percentage of CO_2 in flue gases from side flue of boilers by means of combustion recorder	7·6 per cent.
Steam pressure :—	
Lbs. per square inch (gauge)	89
,, ,, ,, ,, (absolute)	104
Temperature of saturation of steam	330·5° F.
,, ,, superheated steam	346·5° ,,
Steam or power used as auxiliary to the production of steam	2·4 per cent.
Thermal efficiency :—	
(*a*) Net working efficiency complete, after deducting 2·4 per cent. steam or power used as auxiliary to the production of steam	60·09 per cent.
(*b*) Boilers only	56·71 ,, ,,
(*c*) Economisers only	4·35 ,, ,,
(*d*) Superheaters ,,	0·51 ,, ,,

B. *Long Check Test* (one week of 7 days) :—

Duration	167·5 hours
Amount of fuel used	128·25 tons
Water evaporated	184,435·0 galls.
,, ,, per lb. coal	6·42 lbs.

Taking separate industries, I gave in "Engineering" (25th July and 1st August, 1919, "Exact Data on the Running of Steam Boiler Plants, No. 2. The Performance of

Colliery Steam Boiler Plants") the detailed figures for the tests of 100 different colliery boiler plants, representing 57[illegible] boilers with an annual coal bill of 1,250,000 tons. These colliery plants were situated as follows:—

Lancashire	14
Derbyshire	8
Gloucestershire	1
Notts	7
Shropshire	1
Scotland	8
South Wales	17
Staffs	26
Yorkshire	17
Warwickshire	1

The true average figures for these 100 tests are given below:—

A. *Working Day's Test*:—

Duration of test	9·68 hrs.
Type of boiler	Chiefly "Lanc."
Number of boilers	Average 5·7
Grate area	217·6 sq. ft.
Number of tubes in economiser	Average 50.
Analysis of coal used:—	
B.Th.U.	10,500
Ash	15·5 per cent.
Amount of coal burnt	39,815 lbs.
Coal burnt per boiler per hour	721·5 ,,
,, ,, ,, sq. ft. grate area per hour	18·9 ,,
Draught:—	
Chimney base	0·95 ins. W.G.
Side flues	0·60 ,, ,,
Temperature of flue gases:—	
Before economiser	690° F.
After ,,	660° ,,
Percentage of CO_2	7·5 per cent.
Total water evaporated	21,693 gals.
Water evaporated per boiler per hour	393 gals.
Temperature of feed-water:—	
Before economiser	137° F.
After ,,	154° ,,
Per cent. saving due to economisers	1·6 per cent.
Steam pressure gauge	86 lbs.
Temperature of saturated steam	328·4° F.
,, ,, superheated steam	350·0° ,,
Steam or power used as auxiliary to the production of steam	1·8 per cent.
Lbs. water per lb. coal	5·44 lbs.
,, ,, ,, from and at 212° F. per lb. coal	6·07 ,,
,, ,, ,, ,, ,, ,, ,, ,, 1,000,000 B.Th.U.	578·1 ,,
Efficiency:—	
(*a*) Net working	55·52 per cent.
(*b*) Boilers only	55·02 ,,
(*c*) Economisers only	0·90 ,,
(*d*) Superheaters ,,	0·62 ,,

B. *Long Check Test (one week of 7 days)* :—

Duration of test	168·00 hrs.
Amount of coal burnt	235·2 tons
" " water evaporated	273,990 gals.
Water evaporated per lb. of coal	5·19 lbs.
Approximate annual coal bill	11,800 tons

The figures can be divided as follows :—

Net Working Efficiency. (Boilers, Economisers and Superheaters.)	No. of Plants.
1. 80 per cent. and over	0
2. 75 " " " "	0
3. 70 " " " "	1
4. 65 " " " "	4
5. 60 " " " "	9
6. 55 " " " "	29
7. 50 " " " "	22
8. Below 50 per cent.	35
Total	100

The average net working efficiency of 55·52 per cent. is the lowest of any industry in the country, although not so low in comparison as is generally supposed. One reason why the efficiency of colliery boiler plants in general is lower than the average, is that there is still at work a number of the grossly inefficient "egg-ended" boilers. I will deal later with the efficiency of different boilers, but out of the 570 boilers in these 100 colliery tests, 37 boilers were of the "egg-ended" variety, 500 being "Lancashire," 31 "water-tube" and 2 special boilers. The second reason is that coal at the colliery, until a few years ago, was so cheap as hardly to be worth saving, and consequently the boiler plant was regarded as even of less importance than usual, whilst also to some extent inferior coal is used.

Also in the "Chemical Trade Journal" of August and September, 1920 ("Coal Saving in the Chemical Industry"), I published the detailed figures for the tests of sixty different chemical works' boiler plants, representing 236 boilers with an annual coal bill of 620,000 tons per annum. The true average figures for these sixty tests are as follows :—

A. *Working Day's Test*:—

Duration of test	9·2 hrs.
Type of boiler	Chiefly "Lanc."
Number of boilers	Average 3·9
Grate area	156·5 sq. ft.
Number of tubes in economiser	Average 300
Analysis of coal used :—	
B.Th.U.	11,350
Ash	12 per cent.
Amount of coal burnt	38,025 lbs.
Coal burnt per boiler per hour	1059·8 ,,
,, ,, ,, sq. ft. grate area per hour	26·6 ,,
Draught :—	
Chimney base	0·70 in. W.G.
Side flues	0·38 ,, ,,
Temperature of flue gases :—	
Before economiser	650° F.
After ,,	450° ,,
Percentage of CO_2	8·0 per cent.
Total water evaporated	23,358 gals.
Water evaporated per boiler per hour	651 ,,
Temperature of feed-water :—	
Before economiser	103° F.
After ,,	215° ,,
Per cent. saving due to economisers	10·1 per cent.
Steam pressure (gauge)	102 lbs.
Temperature of saturated steam	339·2° F.
,, ,, superheated steam	384·2° ,,
Steam or power used as auxiliary to the production of steam	6·1 per cent.
Lbs. water per lb. coal	6·1 lbs.
,, ,, from and at 212° F. per lb. coal	7·0 ,,
,, ,, ,, ,, ,, ,, ,, 1,000,000 B.Th.U.	616·7 ,,
Efficiency :—	
(*a*) Net working	57·9 per cent.
(*b*) Boilers only	54·2 ,, ,,
(*c*) Economisers only	6·1 ,, ,,
(*d*) Superheaters ,,	1·3 ,, ,,

B. *Long Check Test* (*one week of 7 days*):—

Duration of test (hours)	164·5
Amount of coal burnt (tons)	145·62
Amount of water evaporated (gallons)	18918·95
Water evaporated per lb. coal	5·89
Approximate annual coal bill	10,596 tons

These figures for the chemical industry can be divided as follows :—

Net Working Efficiency. (Boilers, Economisers, and Superheaters).	No. of Plants.
1. 80 per cent. and over	0
2. 75 ,, ,, ,, ,,	4
3. 70 ,, ,, ,, ,,	3
4. 65 ,, ,, ,, ,,	12
5. 60 ,, ,, ,, ,,	9
6. 55 ,, ,, ,, ,,	13
7. 50 ,, ,, ,, ,,	9
8. Below 50 per cent.	10
Total	60

Taking again another group of allied industries, that of dyeing, bleaching, calico-printing, finishing, and dyeing and cleaning, in the "Textile Manufacturer" of August to March, 1921 ("Coal Saving by Modern Methods of Steam Generation"), I give the detailed results of sixty-five boiler plants in these industries, representing 217 boilers with an annual coal bill of 275,637 tons per annum. The true average figures for these sixty-five tests are as follows:—

A. *Working Day's Test*:—

Duration of test	8·30 hrs.
Type of boiler	Mostly "Lanc."
Number of boilers	Average 3·3
Grate area	118·60 sq. ft.
Number of tubes in economiser	Not stated
Analysis of coal used:—	
B.Th.U.	11,950
Ash	10·5 per cent.
Amount of coal burnt	20,776 lbs.
Coal burnt per boiler per hour	758·5 ,,
,, ,, ,, sq. ft. grate area per hour	21·17 ,,
Draught:—	
Chimney base	0·83 in. W.G.
Side flues	0·39 ,, ,,
Temperature of flue gases before economiser	610° F.
,, ,, ,, ,, after	460° ,,
Percentage of CO_2	7·8 per cent.
Total water evaporated	13,829·9 gals.
Water evaporated per boiler per hour	504·8 ,,
Temperature of feed-water:—	
Before economiser	112·5° F.
After ,,	202·5° ,,
Percentage saving due to economisers	8·3 per cent.
Steam pressure (gauge)	70 lbs.
Temperature of saturating steam	316·5° F.
,, ,, ,, superheated steam	355·0° ,,
Steam or power used auxiliary to the production of steam	2·0 per cent.
Lbs. water per lb. coal	6·65 lbs.
,, ,, from and at 212° per 1,000,000 B.Th.U.	7·60 ,,
Efficiency:—	
(a) Net working	61·41 per cent.
(b) Boilers only	56·33 ,,
(c) Economisers only	5·15 ,,
(d) Superheaters ,,	1·18 ,,

Long Check Test (one week of 7 days):—

Duration of test	163·93 hrs.
Amount of coal burnt	83·82 tons
,, ,, water evaporated	167,717 gals.
Water evaporated per lb. coal	6·5 lbs..
Approximate annual coal bill	4240 tons

The figures for the dyeing, bleaching, calico-printing finishing, and dyeing and cleaning industries can be divide as follows:—

Net Working Efficiency. (Boilers, Economisers and Superheaters.)	No. of Plants.
1. 80 per cent. and over	1
2. 75 " " "	0
3. 70 " " "	4
4. 65 " " "	12
5. 60 " " "	14
6. 55 " " "	12
7. 50 " " "	16
8. Below 50 per cent.	6
Total	65

Finally, I gave in the Annual Number (1921) of the "Papermaker" (March, 1922), the figures for the paper making industry ("Coal Saving in the Papermaking Industry by the Scientific Control of Steam Boiler Plants"), representing forty boiler plants with 112 boilers and an annual coal bill of 291,145 tons per annum. The true average figures for these forty tests are as follows:—

A. Working Day's Test:—

Duration of test	11·12 hrs.
Type of boiler	Mostly "Lanc."
Number of boilers	Average 2·8
Grate area	102·87 sq. ft.
Number of tubes in economiser	216
Analysis of coal used:—	
B.Th.U.	11,530
Ash	12·75 per cent.
Amount of coal used	236,005 lbs.
Coal burnt per boiler per hour	757·9 "
" " " sq. ft. grate area per hour	20·6 "
Draught:—	
Chimney base	0·85 in. W.G.
Side flues	0·45 " "
Temperature of flue gases:—	
Before economiser	600° F.
After "	414° F.
Percentage of CO_2	8·0 per cent.
Total water evaporated	16,873·4 galls.
Water evaporated per boiler per hour	541·9 "
Temperature of feed-water:—	
Before economiser	143° F.
After "	270° "
Percentage saving due to economiser	11·9 per cent.
Steam pressure (gauge)	104 lbs.
Temperature of saturated steam	340·5° F.
" " superheated steam	360·0° "
Steam or power used auxiliary to production of steam	3·75 per cent.
Lbs. water per lb. coal	7·15 lbs.
" " from and at 212° F. per lb. coal	7·95 "
" " " " " " " 1,000,000 B.Th.U.	689·3 "

Efficiency:—

(a) Net working	65·07 per cent.
(b) Boilers only	58·91 ,, ,,
(c) Economisers only	8·01 ,, ,,
(d) Superheaters ,,	0·69 ,, ,,

Long Check Test:—

Duration of test	158·8 hrs.
Amount of coal burnt	125·61 tons
,, ,, water evaporated	189 124 gals.
Water evaporated per lb. coal	6·72 lbs.
Approximate annual coal bill	7278 tons

The figures for the papermaking industry can be divided as follows:—

Net Working Efficiency. (Boilers, Economisers and Superheaters.)	No. of Plants.
1. 80 per cent. and over	0
2. 75 ,, ,, ,, ,,	1
3. 70 ,, ,, ,, ,,	1
4. 65 ,, ,, ,, ,,	6
5. 60 ,, ,, ,, ,,	7
6. 55 ,, ,, ,, ,,	10
7. 50 ,, ,, ,, ,,	8
8. Below 50 per cent.	7
Total	40

I am also tabulating similar figures for various other industries, particularly cotton and woollen manufacture, and the general results are almost identical with the four industries already given.

The striking fact, as will be seen, is that, in averages, individual boiler plants are working at all kinds of efficiencies, actually from 32 to 82 per cent., whilst the average for all the 400 boiler plants is 58 per cent., and the average for individual industries may vary from 55 to 65 per cent. The results being obtained in general can, I think, be conveniently expressed by a series of tables which I gave in "Engineering," 10th to 17th December, 1920 ("Exact Data on the Performance of Steam Boiler Plants, No. 4. Average Figures for the Performance of Some Different Types of Steam Boiler Plant").

In these tables I have given for the various types of boiler in use, first of all—as much the most important—the figures being obtained to-day under average conditions without any proper methods of testing and control, applying to at least

85 per cent. of the boiler plants of the country. I have also given in the case of "Lancashire" and "Water-tube" boilers, corresponding figures for plants run on the most modern lines, which apply only to probably about 5 per cent. of boiler plants, and at the same time I have given figures for very bad plants, probably typical of about 10 per cent. of the plants of the country.

In order to present comparative figures, the coal used throughout has been calculated as 12,000 B.Th.U. per pound gross, and 10·5 per cent. ash, which represents roughly the average quality, or slightly above the average, used throughout the country.

Also, for the purpose of comparison, I have taken an average price of 40s. per ton, and calculated the day's test and the week's test in pence per 1000 gallons, together with a coal bill for a standard evaporation of 20,000,000 gallons of water.

Further, in taking the temperature of the feed-water (as going into the plant) an average figure of 110° F. has been taken throughout, because this is about the usual figure, being the ordinary "hot well" temperature. In studying the figures, therefore, if the temperature of the inlet water of a particular plant is different, every 11° F. can be taken as equivalent to 1 per cent. of the coal consumption, higher or lower. Thus, if the feed-water be about, say, 99° F. then the coal consumption figures will be increased about 1 per cent.

LANCASHIRE BOILER PLANT.

The adjoining table gives what I consider to be the average figures for the performance of the "Lancashire" boiler complete with all accessories, calculated in terms of standard 30 × 8 ft. boilers with average grates 6 × 3 ft. 2 in.

A plant of four boilers is given because this is about the average size and, of course, for a different number of boilers the corresponding figures can easily be calculated.

As regards the method of firing, hand and mechanical firing are averaged together, as there is, in my opinion, little

LANCASHIRE BOILER PLANT.

	Bad Plant Representing, say, 10 Per Cent. of Boiler Plants at Work in Great Britain.	Ordinary Average Plant as being Generally Worked To-day, Representing 85 Per Cent. of Plants at Work in Great Britain.	Most Efficient Plant Working under Modern Scientific Supervision or under Test Conditions, Representing only about 5 Per Cent. of Plants at Work in Great Britain.
A. WORKING-DAY TEST.			
1. Number of boilers working	4	4	4
2. Grate area (total)	151·96 sq. ft.	151·96 sq. ft.	151·96 sq. ft.
3. Duration of test	12 hours	12 hours	12 hours
4. Price of coal used (per ton delivered)	40s.	40s.	40s.
5. Amount of coal used	36,249 lbs.	41,504 lbs.	50,870 lbs.
6. Analysis of coal—B.Th.U.	12,000	12,000	12,000
7. Analysis of coal—ash	10·5 per cent.	10·5 per cent.	10·5 per cent.
8. Coal burned per boiler per hour	755·2 lbs.	864·7 lbs.	1059·8 lbs.
9. Coal burned per sq. ft. grate area per hour	19·8 lbs.	22·7 lbs.	27·9 lbs.
10. Water evaporated, lbs.	204,000 lbs.	276,000 lbs	408,000 lbs.
11. Water evaporated per boiler per hour	4250 lbs.	5750 lbs.	8500 lbs.
12. Water evaporated per sq. ft. grate area per hour	111·3 lbs.	151·3 lbs.	223·7 lbs.
13. Water evaporated per lb. of coal	5·62 lbs.	6·65 lbs.	8·02 lbs.
14. Equivalent evaporation from and at 212° F. per lb. of coal	6·42 lbs.	7·62 lbs.	9·28 lbs.
15. Equivalent evaporation from and at 212° F. per 1,000,000 B.Th.U.	535·1 lbs.	635·0 lbs.	856·7 lbs
16. Temperature of feed-water before economisers	110° F.	110° F.	110° F.
17. Temperature of feed-water after economisers	No economiser	230° F.	335° F.
18. Percentage of coal bill saved by economisers	Nil	11·0 per cent.	20·4 per cent.
19. Draught in back flues of boilers	0·40 in. W.G.	0·35 in. W.G.	0·65 in. W.G.
20. Draught in chimney base	0·50 in. W.G.	0·75 in. W.G.	2·00 in. W.G.
21. Temperature of flue gases before economisers	500° F.	600° F.	650° F.
22. Number of economiser tubes	No economiser	About 320 tubes	About 500 tubes
23. Temperature of flue gases after economisers	500° F.	450° F.	310° F.
24. Analysis of boiler feed-water—			
Degrees permanent	12°	9°	5°
Degrees temporary	5°	2°	0°
25. Percentage CO_2 in flue gases (continuous record on combustion recorder)	5·0 per cent.	7·5 per cent.	12·0 per cent.
26. Steam pressure (average)—(*a*) Gauge	60 lbs.	75 lbs.	159 lbs.
27. Steam pressure (average)—(*b*) Absolute	75 lbs.	90 lbs.	174 lbs.
28. Temperature of saturation of steam	307·4° F.	320·3° F.	37[illegible]° F.
29. Temperature of superheated steam	None	None	540° F.
30. Steam or power used as auxiliary to production of steam	5·0 per cent.	2·5 per cent.	2·5 per cent.
Thermal efficiency of plant—			
31. (*a*) Net working efficiency of plant complete	49·2 per cent.	60·0 per cent.	79·0 per cent.
32. (*b*) Boilers only	51·8 per cent.	51·7 per cent.	59·5 per cent.
33. (*c*) Economisers only	Nil	6·8 per cent.	15·3 per cent.
34. (*d*) Superheaters only	Nil	Nil	6·2 per cent.
35. Cost in coal to evaporate 1000 gals. of water	380·8d.	332·6d.	266·9d.
B. LONG CHECK TEST (ONE WEEK). (Say Two Shifts per 24 Hours.)			
36. Duration	168·0 hours	168·0 hours	168·0 hours
37. Price of coal used (per ton delivered)	40s.	40s.	40s.
38. Amount of coal used	120 tons	140 tons	230 tons
39. Water evaporated	149,180 gals.	203,840 gals.	404,430 gals.
40. Water evaporated per lb. of coal	5·55 lbs.	6·50 lbs.	7·85 lbs.
41. Cost in coal to evaporate 1000 gals of water	386[illegible]d.	329·6d.	273·0d.
42. Coal bill for 20,000,000 gals. evaporated per annum	£3[illegible],166	£27,172	£22,748

difference in efficiency between the two methods. I propose to deal with this question more in detail on page 42.

With regard to the following points :—

1. **Coal Burnt per Boiler per Hour.**—Calculated as 12,000 B.Th.U. coal the average figures can be taken as about 865 lbs. per 30 × 8 ft. boiler per hour, corresponding to about 22¾ lbs. per square foot grate area per hour. A very bad plant will, as seen, burn less than this, whereas a plant on modern lines would give about 20 per cent. more duty in this respect.

2. **Water Evaporated per Boiler per Hour.**—Calculated at 110° F. inlet temperature, the average is just below 6000 lbs. per 30 × 8 ft. boiler. This is considerably less than is generally supposed, and most steam users imagine that something like 8500 lbs. is the figure being obtained ; this, however, does not apply to more than about 5 per cent. of the plants of the country. In general, the boiler plants of Great Britain are working at nothing like their proper output, which is interesting in view of the fact that hundreds of works are at the same time in continual trouble due to shortage of steam.

3. **Water Evaporated per Pound of Coal.**—This, of course, depends on the heating value of the coal and the temperature of the feed-water, but taking as usual the averages of 12,000 B.Th.U. and 110° F. the figure is 6·65 lbs. corresponding to 7·62 lbs. from and at 212° F. For all practical purposes, the figure can be taken as 6·5 lbs. corresponding to 7·5 lbs. from and at 212° F. For bad plants and especially those without economisers, the figures are, say, 5·5 and 6·5 lbs. respectively. Figures like 9 to 10 lbs. of water from and at 212° F. per lb. of coal, which are popularly imagined to apply to most boiler plants, only apply to about 5 per cent. of the plants of the country.

4. **Draught.**—The draught of the average boiler plant is obtained by means of a chimney (natural draught) giving a draught in the base of about 0·75 in. suction water gauge, which, with the average flues and economisers corresponds to

about 0·35 in. water gauge in the side flues. The height of a chimney corresponding to these figures is, roughly, say, 125 to 150 ft. with average flues. In the case of bad plant, a short chimney, say, 90 to 120 ft., and cramped and defective flues, the draught corresponds to only about 0·5 in. water gauge in the chimney base. Without economisers this is equal to, say, 0·4 in. in the side flues. If economisers are installed under such conditions, say, an average of 320 tubes for 4 boilers, there is a very serious reduction in the draught, and in the side flues the figure would then only be about 0·20 in. water gauge. On a good plant, using mechanical-induced draught, the figure averages about 2 ins. water gauge in the flue near the fan inlet, and 0·65 in. water gauge in the side flues, much thicker fires being used.

5. **Temperature of Flue Gases.**—The gases leaving the boilers average about 600° F. with coal of 12,000 B.Th.U. On a bad plant with a poor draught and leaky brickwork, the figure is only about 500° F., chiefly because of cold air leakages. In a most efficient plant the figure goes up to, say, 650° F., because of tight brickwork and good fires with a minimum of excess air. With too much draught or "short circuiting" of the gases in the boiler seatings, however, the temperature may go as high as 800° F. leaving the boiler.

6. **Quality of Feed-Water.**—The average figures for feed-water are about 11° total hardness, that is 11 grains per gallon, and this means a considerable deposit of scale with a corresponding loss in efficiency. It is difficult to express the advantage of softening the feed water in figures of annual saving in the coal bill, but a good plant should not have have a hardness of over 5° to 6°, and a softening plant is necessary in average cases to obtain such figures. A typical average bad plant has, say, 17 grains per gallon, which of course means serious scale troubles.

7. **Percentage of CO_2.**—The average plant is only giving, say, 7·5 per cent. CO_2 in the side flues, because of medium firing and leaky brickwork, whilst a very efficient plant is

about 12 per cent. It must be remembered, however, that high CO_2 does not mean efficiency unless at the same time there is no CO (carbon monoxide) present, and the figure for CO_2 is apt, therefore, to be deceptive. In averages the figures for CO are, say, 0·1 to 0·35 per cent., and in good cases 0·1 to 0·2 per cent., bad cases being over 1 per cent.

8. **Economisers.**—As will be discussed later, the average saving in practice due to economisers is nothing like so great as commonly imagined, averaging about 11 per cent. of the coal bill instead of 15 to 20 per cent. as usually stated by economiser makers. For the "Lancashire" boiler plant to-day of four boilers, 30 × 8 ft., 320 tubes, 9 ft. tubes, may be regarded as representing average practice, giving 11 per cent. saving in the coal bill, and raising the feed-water from 110° to 230° F. As previously stated, in calculating the saving, roughly 11° F. rise in the feed-water corresponds to 1 per cent. saving in the coal bill. The installation of economisers chokes the draught in the case of chimney draught, because of the reduction in the temperature of the gases at the chimney base. Thus, taking a typical case of a chimney 170 ft. high, with gases 600° F. in the base, giving 1·14 in. W.G. at the chimney base, if economisers are installed and the flue gases reduced in temperature to 350° F. the draught would then only be, say, 0·70 in. water gauge. In a plant run on the most up-to-date lines the saving can average 18 to 20 per cent., and 17·5 per cent. can be taken as a fair average figure for a good economiser installation, if modern scientific methods of control are adopted throughout.

9. **Superheaters.**—Expressed in averages, the ordinary "Lancashire" boiler plant can be stated to be working without superheaters, and the boiler plants of Great Britain make very little use of superheating. When installed, a rough calculation is, say, 0·05 per cent. saving in the coal bill for every 1° F. rise in the temperature of the steam above saturation point. A plant on modern lines will superheat the steam to, say, 170° to 200° F. above saturation point, and reduce the coal bill

9 to 10 per cent. in addition, of course, to the extra efficiency in the engine or turbine.

10. **Steam or Power Used Auxiliary to the Production of Steam.**—As will be discussed later (p. 45), the amount of steam used by steam jets is much greater than is commonly supposed. The average figure we found to be 6·6 per cent. of the steam production of the plant, being the same for both mechanical stokers and hand-fired steam-jet furnaces, the general impression being that it is only about 1 to 2 per cent. On individual plants the figure may be anything from 0·5 to 20 per cent., and more detailed figures are given on page 104. Mechanical forced, or induced draught generally takes about 2·5 per cent. of the production at full output. As we have no proper engineering census, it is difficult to give average figures for auxiliary steam or power consumption, because it is not known what proportion of the boiler plants of the country use such apparatus. I estimate roughly that the figure is 35 per cent. of the plants of Great Britain, and 2·5 per cent. for the steam consumption for auxiliary power for the whole of the plants of the country is probably not far wrong. I have taken the bad plants as 5 per cent., and 2·5 per cent. would still be required by the most up-to-date plant. Naturally, in calculating the net working efficiency of a boiler plant such steam has to be deducted, as it is not useful steam, a point which will also be discussed later.

11. **Efficiency of Plant.**—In averages, a "Lancashire" boiler plant is working at, say, 54·5 per cent. for the boilers only, and 60 per cent for the whole plant, including economisers and superheaters, and deducting 2·5 per cent. for the auxiliary steam. Bad plants may be about 50 per cent. net working efficiency. As already seen, this is very much less than is commonly supposed, the usual empirical figures in general use corresponding to about 75 to 80 per cent. net working efficiency, which is entirely erroneous. A modern plant will give about 60 per cent. efficiency on the boiler only, corresponding to about 79 per cent. net working efficiency,

WATER-TUBE BOILER PLANT.

	Bad Plant Representing, say, 10 Per Cent. of Boiler Plants at Work in Great Britain.	Ordinary Average Plant as being Generally Worked To-day, Representing 85 Per Cent. of Plants at Work in Great Britain.	Most Efficient Plant Working under Modern Scientific Supervision or under Test Conditions, Representing only about 5 Per Cent. of Plants at Work in Great Britain.
A. Working-Day Test.			
1. Number of boilers working	4	4	4
2. Grate area (total)	560·0 sq. ft.	560·0 sq. ft.	560·0 sq. ft.
3. Duration of test	12 hours	12 hours	12 hours
4. Price of coal used (per ton delivered)	40s.	40s.	40s.
5. Amount of coal used	139,765 lbs.	141,040 lbs.	137,275 lbs.
6. Analysis of coal—B.Th.U.	12,000	12,000	12,000
7. Analysis of coal—ash	10·5 per cent.	10·5 per cent.	10·5 per cent.
8. Coal burned per boiler per hour	2911·7 lbs.	2938·3 lbs.	2859·9 lbs.
9. Coal burned per sq. ft. grate area per hour	20·8 lbs.	20·9 lbs.	20·4 lbs.
10. Water evaporated, lbs.	898,656 lbs.	989,352 lbs.	1,081,200 lbs.
11. Water evaporated per boiler per hour	18,722·0 lbs.	20,611·0 lbs.	22,525·0 lbs.
12. Water evaporated per sq. ft. grate area per hour	133·7 lbs.	147·2 lbs.	160·9 lbs.
13. Water evaporated per lb. of coal	6·43 lbs.	7·01 lbs.	7·87 lbs.
14. Equivalent evaporation from and at 212° F. per lb. of coal	7·46 lbs.	8·12 lbs.	9·11 lbs.
15. Equivalent evaporation from and at 212° F. per 1,000,000 B.Th.U.	621·6 lbs.	676·6 lbs.	759·2 lbs.
16. Temperature of feed-water before economisers	110° F.	110° F.	110° F.
17. Temperature of feed-water after economisers	No economisers	195° F.	225° F.
18. Percentage of coal bill saved by economisers	None	7·1 per cent.	10·4 per cent.
19. Draught in back flues of boilers	0·70 in. W.G.	0·35 in. W.G.	0·30 in. W.G.
20. Draught in chimney base	0·75 in. W.G.	0·50 in. W.G.	0·65 in. W.G.
21. Temperature of flue gases before economisers	575° F.	475° F.	450° F.
22. Number of economiser tubes	None	200	250
23. Temperature of flue gases after economisers	575° F.	325° F.	300° F.
24. Analysis of boiler feed water—			
Degrees permanent	9°	6°	3°
Degrees temporary	2°	2°	0°
25. Percentage CO_2 in flue gases (continuous record on combustion recorder)	5·0 per cent.	6·0 per cent.	12·5 per cent.
26. Steam pressure (average)—(*a*) Gauge	150 lbs.	155 lbs.	160 lbs.
27. Steam pressure (average)—(*b*) Absolute	165 lbs.	170 lbs.	175 lbs.
28. Temperature of saturation of steam	365·9° F.	368·3° F.	370·5° F.
29. Temperature of superheated steam	450·0° F.	530·0° F.	650·0° F.
30. Steam or power used as auxiliary to production of steam	2·5 per cent.	2·9 per cent.	1·5 per cent.
Thermal efficiency of plant—			
31. (*a*) Net working efficiency of plant complete	61·0 per cent.	69·2 per cent.	[illegible]9 per cent.
32. (*b*) Boilers only	59·9 per cent.	60·3 per cent.	65·8 per cent.
33. (*c*) Economisers only	None	4·9 per cent.	7·6 per cent.
34. (*d*) Superheaters only	2·6 per cent.	5·4 per cent.	9·7 per cent.
35. Cost in coal to evaporate 1000 gals. of water	333·2d.	305·3d.	272·0d.
Long Check Test (One Week). (Say Two Shifts per 24 Hours.)			
36. Duration	168 hours	168 hours	168 hours
37. Price of coal used (per ton delivered)	40s.	40s.	40s.
38. Amount of coal used	458·2 tons	452·0 tons	467·5 tons
39. Water evaporated	651,740 gals.	703,674 gals.	815,769 gals.
40. Water evaporated per lb. of coal	6·35 lbs.	6·95 lbs.	7·79 lbs.
41. Cost in coal to evaporate 1000 gals. of water	337·4d.	308·3d.	275·0d.
42. Coal bill for 20,000,000 gals. evaporated per annum (say 220 tons of coal per week)	£28,120	£25,688	£22,920

although individual "Lancashire" boiler plants can be worked at 80 per cent. net working efficiency, or even over. This, as seen, includes the full use of economisers and super-heaters, but allowing also for any mechanical draught with the consequent 2·5 per cent. auxiliary steam required to drive the fan.

These figures can, in general, be said to apply to all large cylindrical boilers such as "Cornish" and "Marine" boilers, and the various adaptions of such boilers with smaller tubes used in conjunction with the ordinary standard furnace tubes.

WATER-TUBE BOILER PLANT.

The corresponding figures for water-tube boiler plants are given on the adjoining page, calculated for standard sized water-tube boilers with a rated evaporation of 20,000 lbs. water per hour each, say, about 5250 sq. ft. of heating surface, with grates 14 × 5 ft., taking as a typical plant five or six such boilers, four working at a time. The boilers are fired by mechanical stokers, as very few water-tube boilers are hand-fired, except small boilers of, say, 10,000 lbs. hourly evaporative capacity. When fitted with economisers, each boiler has its own separate set of economisers, the present standard practice. The water-tube boiler plant may be said to be the typical power station plant, and is also installed in many factories where high steam pressure is required. There are, of course, a considerable number of different makes of water-tube boilers on the market, some of which give more efficient results than others, but I have endeavoured to give average figures for water-tube boilers generally.

1. **Coal Burnt per Boiler per Hour.**—Calculated as 12,000 B.Th.U. coal, the average figures can be taken as about 28,000 lbs. (say 1·25 tons) per hour (20,000 lbs. boiler as already stated), corresponding to 20·5 lbs. per sq. ft. grate area per hour. The rate of consumption of coal on the average water-tube boiler is roughly about the same, irrespective of the results being obtained.

2. **Water Evaporated per Boiler per Hour.**—In averag

plants the rated evaporation is being obtained, namely 20,000 lbs. per hour, and on very efficient plants the boiler plant is often working regularly on 10 to 20 per cent. overload. It is only on very bad plants that the nominal evaporation is not being obtained, and there is not the same difference in evaporation between different water-tube boiler plants as there is with cylindrical boiler plants.

3. **Water Evaporated per Pound of Coal.**—Calculated as usual on 12,000 B.Th.U. coal and 110° F. feed-water, the average figure is 7 lbs. of water per lb. of coal, corresponding to, say, 8 lbs. of water from and at 212° F. On bad plants the corresponding figures are 6·5 and 7·5 lbs. Here again, the average figures usually taken, such as 10 lbs. of water from and at 212° F. are quite erroneous, and only apply to a few plants.

4. **Draught.**—For the average water-tube boiler plant the standard practice is to use mechanical induced or forced draught, or a combination of both, with a short steel chimney, say, 60 to 100 ft. high. In such cases the draught in the flue near the fan inlet is only about 0·5 in. W.G., very much less than induced draught for cylindrical boilers. Roughly, the same figures apply to a most modern plant, whilst on a bad plant the draught is often greater. A number of water-tube boiler plants are worked on chimney draught only, especially small plants, but the draught obtained in practice is not much less, as a comparatively high chimney is then generally used.

5. **Temperature of Flue Gases.**—In the average water-tube boiler plant the gases leave the boiler at about 470° F., corresponding to about 325° F. in the chimney base, which is very much less than in the case of cylindrical boilers. In the case of a bad plant the gases may go up to, say, 575° F. leaving the boiler, but this is exceptional, and in very good plants the temperature may be only 450° F. leaving the boiler, and 300° F. leaving the plant.

6. **Quality of Feed-Water.**—As is well known, scale is much more serious for water-tube boilers than for cylindrical

boilers, and there is considerable amount of trouble with water-tube boilers because of scale. In average cases, the total hardness can be taken as 8°, and in bad plants ordinary feed-water at, say, 12° hardness is used regularly. With a modern softening plant, which reduces the make-up water to 5° to 6° hardness, and the use of engine or turbine condensate, the feed-water should not average more than 3° hardness.

7. **Percentage of CO_2.**—The average percentage of CO_2 on water-tube boilers with mechanical stokers is low, averaging about 6 per cent., less than "Lancashire" or other cylindrical boilers. In the chain grate type of stoker the fires tend to burn thin at the back and a large excess of air passes, so that even on the 10 per cent. of bad plants the CO_2 figure is practically as good as the 85 per cent. average plants. On the 5 per cent. of good plants this error is avoided, the figure being about 12·5 per cent.

8. **Superheaters.**—The average water-tube boiler installation makes much better use of superheaters than cylindrical boiler installations, and the average figures for superheat can be taken as, say, 160° to 200° F. Even a poor plant is almost invariably fitted with superheaters, as it is the custom for the boiler maker to include superheaters as part of the installation of the boiler. In a very modern plant very high figures are obtained, say 650° F. final temperature, corresponding to about 250° to 280° superheat.

9. **Economisers.**—Economisers give less saving on a water-tube plant than with cylindrical boilers, because more heat is retained by a water-tube boiler, leaving less to be absorbed by the economiser. Thus, in average cases, the number of tubes in the economiser for a 20,000 lbs. boiler is 200, the feed-water being heated from 110° F. to, say, 195° F., saving 7·4 per cent. of the coal bill. On a poor plant no economisers are installed, whilst on a most modern plant the saving reaches, say, 10·[illegible] per cent. with a temperature of 225° F. in the feed-water leaving the economiser.

10. **Steam or Power Used Auxiliary to the Production**

of Steam.—It is almost the universal custom, as already stated, to work water-tube boiler plants with mechanical forced or induced draught, and steam jets are consequently not much used. The figures for auxiliary steam or power varies from 0·5 to 2·5 per cent. of the production in all classes of plants.

11. **Efficiency of Plant.**—On the average, a water-tube boiler plant is working at, say 60 per cent. efficiency for the boilers only, and 69 per cent. for the whole plant, including economisers and superheaters, and deducting the power used auxiliary to the production of steam. Bad plants may only give a total of about 60 per cent. net working efficiency. These figures, again, are very much less than is usually supposed. It is a common belief that, generally speaking, a water-tube boiler plant is very much more efficient than a cylindrical boiler plant, and that more or less all water-tube boiler plants are efficient. This idea is entirely wrong. Figures like 80 to 82 per cent. net working efficiency, with 65 per cent. due to the boiler only, and 9 lbs. of water from and at 212° F. per lb. of coal, are only obtained by a few plants, although, of course, possible on most water-tube plants. As already stated, a cylindrical boiler plant will run on 77·5 to 80 per cent. under good conditions, whilst the average is 60 per cent. It should be remembered also that the wear and tear and cost of upkeep is, on the average, considerably greater than "Lancashire" boilers.

Small Cylindrical Boiler Plant.

There are hundreds of such installations scattered about the country in small works, hotels and hydros, various public institutions, etc., with an average coal bill of, say, 10 to 20 tons a week, generally consisting of one or two small "Lancashire" boilers of some such dimensions as 15 to 20 ft. by 5 ft. 6 ins. or 6 ft., or one or two small "Cornish" boilers of similar dimensions, hand-fired, working without economisers, and with a very small chimney.

The average figures for these plants are given on the adjoining page.

SMALL CYLINDRICAL BOILER PLANT.

A. *Working-Day Test.*	Ordinary Average Plant as Generally being Worked To-day.
1. Number of boilers working	2 "Lancashire"
2. Grate area (total)	40 sq. ft.
3. Duration of test	12 hours
4. Price of coal used (per ton delivered)	40s.
5. Amount of coal used	8326 lbs.
6. Analysis of coal—B.Th.U.	12,000
7. " " " Ash	10·5 per cent.
8. Coal burned per boiler per hour	346·8 lbs.
9. " burnt per square foot grate area per hour	17·3 "
10. Water evaporated, lbs.	48,840 "
11. " " per boiler per hour	2,035 "
12. " " " square foot grate area per hour	101·7 "
13. " " " lb. of coal	5·86 lbs.
14. Equivalent evaporation from and at 212° F. per lb. of coal	6·71 "
15. Equivalent evaporation from and at 212° F. per 1,000,000 B.Th.U.	559·2 "
16. Temperature of feed-water before economisers	110° F.
17. " " " after "	Nil (No economisers)
18. Percentage of coal bill saved by economisers	Nil
19. Draught in back flues of boilers	0·50 in. W.G.
20. " " chimney base	0·25 " "
21. Temperature of flue gases before economisers	590° F.
22. Number of economiser tubes	No economisers
23. Temperature of flue gases after economisers	" " (*i.e.*, 590° F.)
24. Analysis of boiler feed water—	
Degrees permanent	9°
" temporary	2°
25. Percentage CO_2 in flue gases (continuous record on combustion recorder)	5 per cent.
26. Steam pressure (average)—(*a*) Gauge	70 lbs.
27. " " " (*b*) Absolute	85 "
28. Temperature of saturation of steam	316·1° F.
29. " " superheated steam	No superheat
30. Steam or power used as auxiliary to production of steam	None
Thermal efficiency of plant—	
31. (*a*) Net working efficiency of plant complete	54·1 per cent.
32. (*b*) Boilers only	" " "
33. (*c*) Economisers only	Nil
34. (*d*) Superheaters	"
35. [illegible] ate 1000 gallons of water	365·2d.
[illegible] Test (One Week). [illegible] per 24 Hours.)	
36. [illegible]	168 hours
37. [illegible] ton delivered)	40s.
38. Amount [illegible]	17·5 tons
39. Water evapora[illegible]	21,952 gals.
40. " " per lb. of coal	5·60 lbs.
41. Cost in coal to evaporate 1000 gallons of water	382·5d.
42. Coal bill for 20,000,000 gallons evaporated per annum (say, 220 tons of coal per week)	£31,886

Such small boiler installations are all worked more or less on the same general lines, the boiler attendant combining the work of firing the boiler with other duties, so that the attention received is not continuous. The amount of coal burnt can be taken as an average of 17 lbs. per sq. ft. of grate area per hour, with grates 4 × 5 ft., and coal as before, averaging 12,000 B.Th.U. per pound. As regards evaporation this can best be estimated from the average figures of an evaporation of, say, 5·75 lbs. of water at 110° F. per lb. of coal, corresponding to 6·75 lbs. of water from and at 212° F. Thus, on a small "Lancashire" boiler of 15 × 5 ft. 6 ins., the figure is about 200 gallons per boiler per hour. The draught is usually about 0·5 in. suction water gauge in the chimney base, the chimney being small, say, averaging 50 to 75 ft., and on such small mechanical draught is practically never used.

Also, it is not general practice to use steam jet furnaces on these plants, but if present, the average figure for the steam consumption of the jets will be 5 to 10 per cent. of the production of the plant, with a corresponding drop in efficiency. The temperature of the flue gases in the chimney base averages about 600° F. and, as before, the average hardness of the water can be taken as 11° total hardness. Economisers and superheaters are practically never installed, but if present, the saving due to these can be calculated as already shown, namely, 11° F. rise in the feed-water, corresponding to 1 per cent. saving in the coal bill, and 1° F. rise in the superheat equals 0·05 per cent. saving. The net working efficiency is about 54 per cent. and probably does not vary more than between 50 to 60 per cent. on any individual plant.

SMALL VERTICAL BOILER PLANT.

This is a class of boiler largely used in many industries, particularly in engineering works, by builders and contractors, on farms and in small establishments of every description, and the average results being obtained are as given on the adjoining page.

SMALL VERTICAL BOILER PLANT.

	Ordinary Average Plant as Generally being Worked To-day.
A. *Working-day Test.*	
1. Number of boilers working	1
2. Grate area (total)	—
3. Duration of test	12 hours
4. Price of coal used (per ton delivered)	40s.
5. Amount of coal used	1353 lbs.
6. Analysis of coal—B.Th.U.	12,000
7. " " " Ash	10·5 per cent.
8. Coal burned per boiler per hour	112·75 lbs.
9. " burnt per square foot grate area per hour	—
10. Water evaporated, lbs.	7103 lbs.
11. " " per boiler per hour	591·9 "
12. " " " square foot grate area per hour	—
13. " " " lb. of coal	5·25 lbs.
14. Equivalent evaporation from and at 212° F. per lb. of coal	6·01 "
15. Equivalent evaporation from and at 212° F. per 1,000,000 B.Th.U.	500·9 "
16. Temperature of feed-water before economisers	110° F.
17. " " " after "	Nil (No economisers)
18. Percentage of coal bill saved by economisers	Nil
19. Draught in back flues of boilers	0·25 in. W.G.
20. " " chimney base	0·30 " "
21. Temperature of flue gases before economisers	800° F.
22. Number of economiser tubes	No economisers
23. Temperature of flue gases after economisers	" " (*i.e.*, 800° F.)
24. Analysis of boiler feed water—	
Degrees permanent	9°
" temporary	2°
25. Percentage CO_2 in flue gas (continuous record on combustion recorder)	5 per cent.
26. Steam pressure (average)—(*a*) Gauge	70 lbs.
27. " " " (*b*) Absolute	85 "
28. Temperature of saturation of steam	316·1° F.
29. " " superheated steam	No superheat
30. Steam or power used as auxiliary to production of steam	None
Thermal efficiency of plant—	
31. (*a*) Net working efficiency of plant complete	48·4 per cent.
32. (*b*) Boilers only	" " "
33. (*c*) Economisers only	Nil
34. (*d*) Superheaters "	"
35. Cost in coal to evaporate 1000 gallons of water	408·1d.
B. *Long Check Test (One Week).* (Say Two Shifts per 24 Hours.)	
36. Duration	168 hours.
37. Price of coal used (per ton delivered)	40s.
38. Amount of coal used	4·5 tons.
39. Water evaporated	5141 gals.
40. " " per lb. of coal	5·10 lbs.
41. Cost in coal to evaporate 1000 gallons of water	420·0d.
42. Coal bill for 20,000,000 gallons evaporated per annum (say, 220 tons of coal per week)	£35,000

Vertical boilers are usually worked with a short metal chimney, often aided by a steam jet in the chimney base, and hand fixed.

As regards evaporation, this can be taken as being about 5·25 lbs. of water at 110° F. per lb. of coal, corresponding to 6 lbs. of water from and at 212° F. Very roughly, such boilers burn about 1 cwt. of coal an hour and evaporate about 60 gallons of water. The draught in the base of the small chimney is usually, say, 0·30 in. suction water gauge, but can be higher if a steam jet is used. The temperature of the flue gases is usually very high, averaging 800° F. whilst the percentage of CO_2 is about 5. Such plants are worked without superheaters, and of course, economisers, and further, steam jet forced draught furnaces are rarely applied. The average net working efficiency can be taken as about 48 to 50 per cent.

Egg-Ended Boiler.

This boiler was invented somewhere about the year 1780, probably by Richard Trevithick, Senior, the father of the more famous Richard Trevithick who invented the "Cornish" boiler, and, as already stated, there are actually still a number of egg-ended boiler plants at work in collieries. How many plants are still running it is not possible to say, but the number seems now to be limited.

The average figures for the performance can be taken as given on the adjoining page.

The usual dimensions of such boilers to-day are generally 30 to 35 ft. long by 5 ft. 6 ins. diameter, with a blow-off pressure of 40 to 60 lbs. They are built high up on the top of a large brick firing chamber, so that the bottom of the boiler is in the flames from the fire beneath, an arrangement known as a "flash" flue, and the top half of the boiler in the open air, not generally insulated in any way. There is only one large firing grate, averaging in length 6 x 6 ft. 6 ins., and in width about 4 ft. 6 ins., and the flames travel along the bottom of the boiler and straight up to the chimney, which is placed just behind the boilers. The height of the chimney

EGG-ENDED BOILER PLANT.

A. *Working-Day Test.*	Ordinary Average Plant as Generally being Worked To-day.
1. Number of boilers working	4
2. Grate area (total)	112 sq. ft.
3. Duration of test	12 hours
4. Price of coal used (per ton delivered)	40s.
5. Amount of coal used	30,240 lbs.
6. Analysis of coal—B.Th.U.	12,000
7. ,, ,, ,, Ash	10·5 per cent.
8. Coal burned per boiler per hour	630 lbs.
9. ,, burnt per square foot grate area per hour	22·5 ,,
10. Water evaporated, lbs.	112,800 lbs.
11. ,, ,, per boiler per hour	2,350 ,,
12. ,, ,, ,, square foot grate area per hour	83·9 ,,
13. ,, ,, ,, lb. of coal	3·73 ,,
14. Equivalent evaporation from and at 212° F. per lb. of coal	4·26 ,,
15. Equivalent evaporation from and at 212° F. per 1,000,000 B.Th.U.	355 lbs.
16. Temperature of feed-water before economisers	110° F.
17. ,, ,, ,, after ,,	Nil (No economisers)
18. Percentage of coal bill saved by economisers	Nil
19. Draught in back flues of boilers	0·90 in. W.G.
20. ,, ,, chimney base	1·00 ,, ,,
21. Temperature of flue gases before economisers	850° F.
22. Number of economiser tubes	No economisers
23. Temperature of flue gases after economisers	,, ,, (*i.e.*, 850° F.)
24. Analysis of boiler-feed water—	
Degrees permanent	12°
,, temporary	5°
25. Percentage CO_2 in flue gas (continuous record on combustion recorder)	3·75 per cent.
26. Steam pressure (average)—(*a*) Gauge	55 lbs.
27. ,, ,, ,, —(*b*) Absolute	70 ,,
28. Temperature of saturation of steam	320·9° F.
29. ,, ,, superheated steam	No superheaters
30. Steam or power used as auxiliary to production of steam	Nil
Thermal efficiency of plant—	
31. (*a*) Net working efficiency of plant complete	34·3 per cent.
32. (*b*) Boilers only	,, ,, ,,
33. (*c*) Economisers only	Nil
34. (*d*) Superheaters ,,	,,
35. Cost in coal to evaporate 1000 gallons of water	574·4d.
B. *Long Check Test (One Week).* **(Say Two Shifts per 24 Hours.)**	
36. Duration	168 hours
37. Price of coal used (per ton delivered)	40s.
38. Amount of coal used	82 tons
39. Water evaporated	67,050 gals.
40. ,, ,, per lb. of coal	3·65 lbs.
41. Cost in coal to evaporate 1000 gallons water	587·0d.
42. Coal bill for 20,000,000 gallons evaporated per annum (say, 220 tons of coal per week)	£48,918

usually averages 100 to 140 ft. The firing is carried out by hand, and the fire-bars generally are of a very heavy type, with very poor air-space. Nothing in the way of steam jet bars or other appliances seems to be used in connection with the firing of this type of boiler. Such a plant was the standard colliery practice not so many years ago. In collieries the boiler feed-water is heated by the exhaust steam of the winding and other engines, and generally goes into the boilers at about 150° to 160° F. average. As already explained, however, a given temperature of 110° F. has been taken for the feed-water for comparison, and the results altered by calculation. This, of course, does not alter the essential figure of the efficiency of the boiler itself.

In a typical egg-ended boiler of 30 to 35 ft. long and 5 ft. 6 ins. diameter, the amount of coal burnt is almost the same as a "Lancashire" boiler 30 × 8 ft., averaging 22·5 lbs. of coal per square foot of grate area per hour. The amount of the evaporation calculated to 110° F. is only about 250 gallons, practically one-third of that of a "Lancashire" boiler 30 × 8 ft. The water, at 110° F., evaporated per lb. of coal is only about 3·75 lbs., corresponding to, say, 4·5 lbs. from and at 212° F. The draught on such boilers is usually good, because the chimneys used are a fair height, as already stated, and the flue gas temperature is very high, say 850° F., because the flames merely go along the bottom of the boiler and straight up the chimney.

The figure for CO_2 is very low, only about 4 per cent., because of the large open grates and the almost invariably bad quality of the brickwork due to the abnormal expansion and contraction. The net working efficiency is about 35 per cent., a shocking figure, and statements such as 6·5 to 8·5 lbs. of water from and at 212° F. per lb. of coal for egg-ended boilers are ridiculous when applied to the present average working conditions.

These average figures for the various types of boilers, expressed in one table for easier comparison, are as follows:—

		Cylindrical Boiler ("Lancashire," etc.).			Water-tube Boiler.			Small Cylindrical Boiler Average.	Small Vertical Boiler Average.	Egg-ended Boiler Average.
		Average Plant 85 Per Cent.	Good Plant, 5 Per Cent.	Bad Plant, 10 Per Cent.	Average Plant, 85 Per Cent.	Good Plant 5 Per Cent.	Bad Plant. 10 Per Cent.			
Coal burnt per boiler per hour	lbs.	864·7	1059·8	755·2	2938·3	2859·9	2911·7	346·8	112·75	630·0
Coal burnt per sq. ft. grate area per hour	lbs.	22·7	27·9	19·8	20·9	20·4	20·8	17·3	—	22·5
Water evaporation per sq. ft. grate area per hour	lbs.	151·3	233·7	111·3	147·2	160·9	133·7	101·7	—	83·9
Water at 110° F. evaporated per lb. of coal		6·65	8·02	5·62	7·01	7·87	6·43	5·86	5·25	3·73
Water from and at 212° F. evaporated per lb. of coal		7·62	9·28	6·42	8·12	9·11	7·46	6·71	6·01	4·26
Water from and at 212° F. per 1,000,000 B.Th.U.	lbs.	635·0	856·7	535·1	670·6	759·2	621·6	559·2	500·9	355·0
Temperature of inlet water	°F.	110	110	110	110	110	110	110	110	110
Temperature of water after economisers	°F.	230	335	no ecn.	195	225	no ecn.	no ecn	no ecn.	no ecn.
Saving due to economisers	per cent.	11·0	20·4	nil	7·4	10·4	nil	nil	nil	nil
Draught in chimney base or fan inlet	in. W.G.	0·75	2·00	0·50	0·50	0·65	0·75	0·50	0·30	1·00
Temperature of gases leaving boiler	°F.	600	650	5[illegible]0	475	450	575	590	800	850
Temperature of gases at chimney base or fan inlet	°F.	450	310	500	325	3[illegible]0	575	590	800	850
Analysis of feed-water—										
Permanent hardness	deg.	9	5	12	6	3	9	9	9	12
Temporary hardness	deg.	2	0	5	2	0	2	2	2	5
Percentage CO_2 in gases leaving the furnaces		7·5	12·0	5·0	6·0	12·5	5·0	5·0	5·0	3·75
Average gauge pressure	lbs.	75	159	60	155	16[illegible]	150	70	70	55
Temperature of saturated steam	°F.	320·3	370·2	307·3	368·2	370·7	365·9	316·1	316·1	302·9
Temperature of superheated steam	°F.	nil	540	nil	550	6[illegible]0	450	450	nil	nil
Steam or power used auxiliary to the production of steam	per cent.	2·5	2·5	5·0	2·0	1·5	2·5	nil	nil	nil
Efficiency—										
Net working	per cent.	60·0	79·0	49·2	69·2	81·9	61·0	54·1	48·4	34·3
Boilers only	per cent.	54·7	59·5	51·8	60·3	65·8	59·9	54·1	48·4	34·3
Economisers only	per cent.	6·8	15·3	nil	4·9	7·6	nil	nil	nil	nil
Superheaters only	per cent.	nil	6·2	nil	5·4	9·7	2·6	nil	nil	nil
Cost in coal to evaporate 1000 gals. of water	pence	332·6	266·9	380·8	305·3	272·0	333·2	365·2	408·1	574·4
Coal bill for 20,000,000 gals. evaporation	£	27,472	22,748	32,166	25,688	22,920	28,120	31,886	35,000	49,818

The great importance of scientific methods in boiler plant management will be realised by the following simple coal balance sheet for Great Britain, being approximate figures allowing for abnormal circumstances due to wars, strikes, exchange troubles and other complications.

GREAT BRITAIN.

(Average annual figures which will probably apply more or less to the next few years.)

Coal Production . . . . 250,000,000 tons
Coal Disposal—

	Tons.	Per Cent. of Total Coal Raised.
(A) *Exported, 25 per cent., as follows:—*		
1. Sold to the colonies and foreign countries .	41,875,000	16·75
2. „ „ ocean-going steamers . . .	13,750,000	5·50
3. „ „ foreign countries as coke . .	3,125,000	1·25
4. „ „ „ „ in the form of manufactured fuel (briquettes, etc.) . .	1,875,000	0·75
5. Sold to coasting steamers	1,875,000	0·75
Total . . .	62,500,000	25·00
(B) *Home Consumption, 75 per cent., as follows:—*		
6. Steam generation:—		
(*a*) Power purposes	60,000,000	24·0
(*b*) Low pressure purposes . . .	30,000,000	12·0
7. Domestic	35,000,000	14·0
8. Coke from coke ovens	20,000,000	8·0
9. Gas works	18,000,000	7·20
10. Railways	15,000,000	6·0
11. General purposes	9,500,000	4·80
Total . . .	187,500,000	75·00

That is to say, we consume 90,000,000 tons of coal per annum, 36 per cent. of the total coal raised, or 48 per cent. of the home consumption, for the one operation of steam generation.

In general, of this huge amount, 6,500,000 tons are being burnt at say 70 per cent. efficiency or over, 13,000,000 tons at say 65 to 70 per cent. efficiency, 15,500,000 tons at say 60 to 65 per cent. efficiency, 21,500,000 tons at 55 to 60 per cent., 18,000,000 tons at 50 to 55 per cent., and 15,500,000 tons at less than 50 per cent.

Now it is possible, in averages, to work steam boiler plants at 75 per cent. net working efficiency.

This is not a theoretical or fantastic figure, but a reasonable and practical basis, such as quite a number of firms have already obtained by the exercise of care and common sense, and with ordinary and well-known plant machinery and appliances. Thus, out of the 400 plants tested, 2 plants are working at 80 per cent. efficiency or over, and 9 plants at 75 per cent. or over, whilst 17 plants are working at 70 per cent. or over. There is obviously something seriously wrong with our general methods of steam generation when 69 plants are actually working at less than 50 per cent. efficiency, a disgraceful performance, whilst another 80 plants are below 55 per cent., and altogether 245 plants are below 60 per cent. We can take almost any industry in the country and if 50 boiler plants are tested, it will be found that the best plant will be 75 to 80 per cent. efficiency, and the figures can be tabulated one under the other until the lowest plant is not more than 45 per cent. or so. It is quite a common experience to find two works in the same industry working under identical conditions, even in the same street, where the boiler plant of one is, say, 65 per cent. efficiency, and the other 55 per cent., that is, the coal bill of one works is, say, 15 per cent. less than the other, so that if one firm is burning 10,000 tons a year, the other man is only burning 8500 tons for the same duty.

The general reason for this lamentable state of affairs is the almost complete failure to realise that steam generation is an important, interesting, and intricate branch of applied science, and that in nearly all industries there is more money to be saved in the boiler house than in any other section of the establishment. Modern scientific principles of steam generation comprise two distinct sections, namely, efficient design and equipment of the boiler plant and scientific methods of control of the working of the plant, so that the best results are obtained. The boiler plants of Great Britain are very defective in both these sections, but the second is much the

more important of the two, and the lack of interest displayed in the intelligent working of boiler plant could not be better illustrated by the fact that there is no recognised method in the country of testing the performance of a plant. It should be the special object of an International Code to encourage the continual testing and scientific control of boiler plant by making the Code eminently practical. I will, of course, discuss this second section in detail in the next chapters of this book, but it will not be without interest to state here briefly the circumstances as regards the lack of proper equipment on the boiler plants of Great Britain.

The boiler itself is of comparatively little importance, and a "Lancashire" or other cylindrical boiler plant will give practically as good results as a water-tube boiler plant. There is, however, a great lack of economisers. In the 250 plants, as already seen, the average saving due to the economisers was only 7·1 per cent. of the coal bill. The detailed figures for the economiser performance I have given in "Engineering," 1st November, 1918 ("Exact Data on the Running of Steam Boiler Plants, No. 1, Economisers"), as follows:—

TABLE SHOWING RESULTS OF WORKING WITH ECONOMISERS.

Division According to Saving Obtained.	No. of Plants.	Average Temperature of Feed-water.		Average Temperature of Flue Gases.		Draught in Inches. W.G.		Steam Pressure-Gauge.	Total Evaporation on Plant per Hour.	No. o Tubes on Plant.
		Before. ° F.	After. ° F.	Before. ° F.	After. ° F.	Chimney Side	Flue Base or Downtake of Blowers.	Lbs. per Sq. In.	Lbs.	
No economiser at all	95	—	—	—	—	—	—	—	—	—
Less than 5 %	14	134	172	568	371	0·85	0·41	80	17,616·0	228
5 to 7½ %	15	123	194	576	423	0·61	0·35	79	15,340·0	203
7½ to 10 %	23	119	261	549	374	0·74	0·33	100	16,630·0	231
10 to 12½ %	33	118	243	583	403	0·88	0·39	106	29,723·0	401
12½ to 15 %	46	110	282	584	379	0·99	0·41	99	19,760·0	280
Over 15 %	24	170	284	610	375	1·35	0·60	119	23,497·0	392
Total	250									

That is, 95 plants had no means of utilising the waste heat of the flue gases, and it will probably not be an exaggeration to say that 25 per cent. of the boiler plants of Great Britain have no economisers at all.

Taking now the 155 plants fitted with economisers, the average saving obtained on these plants was 11·4 per cent. of the coal bill. Only 24 plants or 17 per cent. of plants fitted with economisers were saving 15 per cent. or over of the coal bill, and only 12 plants 17 per cent. or over.

It is the general rule to install economisers on rule-of-thumb lines such as, for example, 72, 96 or 120 tubes per boiler, quite irrespective of the evaporation. For this reason, and also because the draught is apt to be choked, there is in general not sufficient tubes for the best results. An average saving of say 7½ per cent. of the coal bill instead of about 17·5 per cent., which ought to be obtained, means a national loss of about 10 per cent. in the coal bill, or 9,000,000 tons of coal per annum. Also practically no use is made of feed-water heaters, so that any exhaust steam available, such as that from the boiler feed pump, economiser engine, mechanical draught engine, etc., can be usefully employed in heating the feed-water on the way to the economiser. In averages, something like 3 per cent. of the coal bill is lost in this way, say, 2,700,000 tons per annum.

Also, there is a considerable annual loss due to scale in the feed-water, although it is difficult to express this loss in money.

The average hardness of the boiler feed-water of the United Kingdom is about 11 grains per gallon, and taking the average figure of 6·5 lbs. of water evaporated per lb. of coal, this corresponds, at 90,000,000 tons of coal per annum, to an evaporation of 580,000,000 tons of water yearly, and a deposition in the boilers of the United Kingdom of 100,000 tons of scale and other solid material per annum, nearly 2,000 tons a week. It is impossible to get the best results on any boiler plant with scale in the boilers, and we do not pay anything like enough attention to the purification of the feed-water, either by a water softening plant or otherwise.

As regards mechanical stoking, probably about 25 per cent. or 22,500,000 tons, is burnt per annum by means of mechanical stokers instead of hand-firing. I dealt very fully with the question of mechanical versus hand stoking in a recent paper, "Exact Data on the Performance of Mechanical Stokers as Applied to 'Lancashire' and other Narrow-flued Boilers," read before the Institution of Mechanical Engineers on the 19th March, 1920. In this paper was given the detailed figures for the performance of 80 "Lancashire" boiler plants, mechanically fired. The average net working efficiency of these 80 plants was approximately 59 per cent., the boilers only being 53 per cent. In the 250 tests already mentioned 76 per cent. of the plants were hand-fired and 24 per cent. mechanical, and the figures can be divided as follows ("Proceedings of the Institution of Mechanical Engineers," March, 1920, p. 275):—

	80 Plants Mechanically Fired.		250 Plants (76 Per Cent. Hand Firing and 24 Per Cent. Mechanical Firing).	
	No. of Plants.	Per Cent.	No. of Plants.	Per Cent.
Over 80 per cent.	1	1·25	2	0·8
75 to 80 ,, ,,	2	2·50	9	3·6
70 ,, 75 ,, ,,	2	2·50	13	5·2
65 ,, 70 ,, ,,	17	21·25	30	12·0
60 ,, 65 ,, ,,	11	13·75	44	17·6
55 ,, 60 ,, ,,	16	20·00	62	24·8
50 ,, 55 ,, ,,	15	18·75	47	18·8
Less than 50 per cent.	16	20·00	43	17·2
	80	100·00	250	100·0

The average net working efficiency of 350 hand-fired plants is about 60 to 62 per cent. So that on these figures, mechanical stoking is giving actually less efficiency than hand stoking. In my opinion, if all the plants in Great Britain are considered, there is little or no difference between mechanical and hand stoking, and it cannot be said, therefore,

that we are losing much coal, because only 25 per cent. of boiler plants are equipped with mechanical stokers.

Another cause of loss is that full advantage is not taken of mechanical draught, and probably about 90 per cent. of the boiler plants of Great Britain rely on natural or chimney draught. The chimney, unless built very high, and good quality coal is used, is an out-of-date and unscientific contrivance as a draught producer, and other things being equal, the draught simply depends on the temperature in the base, that is, the more heat is lost the better is the draught. When an economiser is installed to prevent this heat loss, the draught is choked because the temperature of the exit gases is reduced.

The extent of this draught reduction is seen by the following actual example :—

Brick chimney 170 ft. high with a temperature in the base of 600° F. working without economisers. The temperature of the gases in a brick chimney is reduced about 2° F. for every 3 ft. in height because of the cooling action of the outside air, so that the average temperature of the hot gases in the whole of the chimney from top to bottom will be about 544° F., taking the outside air as 60° F.

The draught in the chimney base under these conditions, expressed as inches suction water gauge, is very nearly given by the following formula (which includes friction losses) :—

$$P = H\left(\frac{7{\cdot}6}{t} - \frac{7{\cdot}9}{T}\right)$$

where P = inches water gauge
H = Ht. in feet of chimney above the firing level
T = the mean absolute temperature of the chimney gases
t = absolute temperature of the chimney gases

$$\begin{aligned} P &= 170 \times \left(\frac{7{\cdot}6}{60 + 461} - \frac{7{\cdot}9}{544 + 461}\right) \\ &= 170 \times \left(\frac{7{\cdot}6}{521} - \frac{7{\cdot}9}{1005}\right) \\ &= 170 \times (0{\cdot}01458 - 0{\cdot}00786) \\ &= 171 \times (0{\cdot}00672) \end{aligned}$$

= 1·14 in. W.G., which equals about 0·65 – 0·85 in. W.G. in the side flues of a "Lancashire" boiler.

If now we install economisers to reduce the coal bill, say, 17·5 per cent., the temperature of the gases in the chimney base will be reduced from 600° F. to, say, 350° F. This will correspond to an average temperature in the whole of the chimney of about 294° F., and the draught will be as follows:—

$$P = H\left(\frac{7 \cdot 6}{t} - \frac{7 \cdot 9}{T}\right)$$

$$= 170\left(\frac{7 \cdot 6}{60 + 461} - \frac{7 \cdot 9}{294 + 461}\right)$$

$$= 170\left(\frac{7 \cdot 6}{521} - \frac{7 \cdot 9}{755}\right)$$

$$= 170\,(0 \cdot 01458 - 0 \cdot 01046)$$

= 0·70 in. W.G., which equals about 0·35 in. W.G. in the side flues of a "Lancashire" boiler.

In the 250 tests the 155 plants fitted with economisers show an average drop in the flue gas temperature from 581° to 389° F. whilst the draught averages 0·97 in. W.G. in the chimney base, and is reduced to 0·45 in. in the side flue or downtake. The installation of economisers therefore causes a serious reduction in the draught and, for example, on theoretical grounds, if more economisers were installed, and the saving increased to say 22·5 per cent. of the coal bill with the gases cooled to say 250° F. the draught would be so reduced that hardly any coal would be burnt.

Although, as already stated, chimney draught works very well with a high chimney and good quality fuel, so that say 0·35 in. W.G. is sufficient draught in the side flues, the great majority of boiler plants do not possess these advantages. Consequently, in spite of the fact that, in general, sufficient economisers are not installed, hundreds of boiler plants have to work with the economiser bye-pass damper partly open to allow some of the hot gases to go right up the chimney, so as to provide sufficient draught to work the plant. The main advantage of mechanical draught (forced or induced) is that the draught is quite independent of the flue gas temperature, being provided by the

engine or motor driving the fan, which takes the equivalent of about 2·5 per cent. of the steam production of the plant. Consequently, the full amount of heat can be extracted by the economisers, and theoretically the flue gas exit temperature could be reduced to 213° F. to absorb all the heat, and still retain all the water in the flue gases as steam.

A large number of boiler plants (93 plants out of the 250 tested) probably about 35 per cent. of the plants of the country, are working with some form of steam jet furnace, either hand or mechanically fired, which can be called a variation of forced draught. Most of these steam jet furnaces are working in conjunction with natural or chimney draught but a few have mechanical induced draught.

The amount of steam used by the steam jets averages about 6·5 per cent. of the production of the plant and is much too high. I published in "Engineering," 16th January, 1920 ("Exact Data on the Running of Steam Boiler Plants, No, 3. The amount of Steam Used by Steam Jets"), the results of investigation carried out into the working of 130 boiler plants fitted with steam jet furnaces, eleven different types of hand-fired furnace and eight different types of mechanically fired, comprising 437 boilers with a coal bill of about 1,000,000 tons per annum. The results are tabulated on page 46.

It is generally assumed that the amount of steam used by steam jets is small, say 1 to 2 per cent. of the production, but it will be obvious that these figures are quite erroneous, and the amount is much more than is generally realised.

One of the most striking facts is the enormous difference between the amounts of steam used by these steam jets. Thus, the lowest figure obtained was 0·50 per cent. of the production, and the highest 21·4. The differences on different plants using the same make of apparatus are almost as remarkable.

Of the whole 130 plants, twenty-nine have coal bills of over £1000 per annum incurred by the use of steam jets alone, whilst the number of plants with coal bills of £500 or over is forty-seven.

The great cost incurred in average cases in the running of steam jets is not realised. Thus, taking an average sized boiler plant of six "Lancashire" boilers, burning say 12,000 tons of coal per annum, equivalent to £18,000 per annum, with coal

AMOUNT OF STEAM USED BY STEAM JETS.

AVERAGE RESULTS FOR HAND FIRING.

(Net Average 6·6 Per Cent. of the Production.)

Type of Apparatus.	Number of Plants Fitted.	Total Number of Boilers.	Percentage of Production of the Plant used by Jets.	Total Coal Bill of the Plants per Annum. Tons.	Total Coal Bill used by the Jets. Tons.
A.	6	17	7·6	20,200	1535·2
B.	4	7	4·5	15,400	693·0
C.	3	6	7·3	9,234	674·0
D.	18	60	6·3	137,005	8361·5
E.	7	22	8·1	55,450	4491·4
F.	2	3	3·2	5,850	187·2
G.	2	4	5·0	6,600	330·0
H.	2	6	7·7	14,400	1108·0
I.	3	6	4·4	8,525	375·1
J.	1	2	15·25	4,000	610·0
K.	6	16	5·9	35,346	2079·5
Total	54	149		312,010	20715·7

AVERAGE RESULTS FOR MECHANICAL FIRING.

(Net Average 6·7 Per Cent. of the Production.)

Type of Apparatus.	Number of Plants Fitted.	Total Number of Boilers.	Percentage of Production of the Plant used by Jets.	Total Coal Bill of the Plants per Annum. Tons.	Total Coal Bill used by the Jets. Tons.
Sprinkling Stoker.					
A.	25	73	5·0	140,345	7017·2
B.	16	45	5·25	95,550	5016·4
C.	7	23	5·0	30,070	1503·5
Coking Stoker.					
A.	4	12	2·3	21,050	484·1
B.	1	3	13·8	5,750	793·5
C.	13	66	8·0	221,950	17756·0
D.	1	3	7·2	4,900	352·8
E.	9	63	7·5	185,250	13893·7
Total	76	288		704,865	46817·2

at an average price of 30s. per ton. The cost of an ordinary steam jet apparatus hand-fired would be about, say, £100 per boiler, equal to £600 for the plant.

Taking the average figure of 6·6 per cent. of the steam production used by the jets, this corresponds to £1188 per annum as the cost of the steam used, equal to buying an entirely new set of steam jet apparatus for the whole of the six boilers about every six months.

For a similar plant a mechanical stoker equipment would cost about double, say, £2000, and in this case at 6·5 per cent. of the steam production, this would be equivalent to replacing the whole of the stokers, say, every eighteen months. In addition, also, in the latter case the cost of upkeep of the stokers has to be taken into account, whereas the hand-fired steam jet apparatus has the advantage that the fire-bars last a very long time because of the "cooling" action of the steam.

Assuming that 35 per cent. of the boiler plants of the United Kingdom are fitted with steam jet furnaces, this corresponds to 31,500,000 tons of coal burnt per annum, and at 6·6 per cent. of the production of the plant, is equal to about 2,000,000 tons of coal used per annum for the sole purpose of steam generation to supply steam jets. Assuming that the steam jet furnace is the right method for burning 35 per cent. of the coal used for steam generation, then with proper care and attention, the amount of steam used ought to be cut down to 3·5 per cent. of the production, say within the limits of 1·5 to 4 per cent. That is to say, by the careless use of steam jets, and the use of a number of furnaces of bad design, we are wasting per annum about 1,000,000 tons of coal. The question of the advisability of using steam jets at all is a matter of opinion, but in certain cases, such as for coke and coke breeze, and some varieties of refuse coal, they are very useful. Roughly, I should say that under existing conditions of burning raw coal, about 10 per cent. of the boiler plants of the country are suitable for hand-fired steam jet furnaces, whilst the question of mechanical firing is very open.

Finally, as regards superheaters, we do not make anything like the proper use of superheated steam. The value of superheating for fuel economy is in two directions, first, that of partial superheat to, say, 75° F., to reduce condensation losses in the steam pipe circuits, and, secondly, that of high superheat up to 200° F. to improve the efficiency of the steam engine or turbine. Out of the 250 plants tested, only eighty were fitted with superheaters, and of these eighty plants only twenty-five plants were completely equipped, so that the average amount of superheat on the eighty plants was 50° F. (316° F. temperature of saturation to 366° F. on the superheater).

It will not be an exaggeration to say that 5 per cent. of the coal bill, 4,500,000 tons per annum, is lost because of the failure to realise the value of superheating.

Finally, I should like to point out that Great Britain is probably no worse in respect of inefficient steam generation than any other country, and this deplorable state of affairs seems to exist, for example, in America and France also. I have examined about forty boiler plants in France and judging from this short experience, and from information contained in French engineering literature, it would seem that the average net working efficiency of the boiler plants of France is not much more than 60 per cent., and certainly not over 65 per cent. I have no personal experience of boiler plants in America, but judging by the American engineering literature, especially in connection with the efforts made for fuel economy during the war, it would appear that in America also the average net working efficiency of boiler plants does not exceed 60 per cent.

It is painfully interesting to reflect that at least 100,000,000 tons of coal per annum is being lost throughout the world by lack of proper methods of boiler house management.

PART II.

CRITICISMS OF EXISTING CODES AND SUGGESTIONS FOR AN IMPROVED INTERNATIONAL CODE.

1. **The Necessity of Having an Entirely Separate Code for Boiler Plant Testing.**—It is, in my opinion, a fundamental mistake in the "Civils" Code to lump together boiler plant and steam engine tests, and this error is not committed to anything like the same extent in the American "Mechanicals" Code, which is divided sharply into separate test codes for boilers, reciprocating steam engines, steam turbines, pumping machinery, compressors, blowers and fans, steam power plants, locomotives, gas producers, gas and oil engines, and water-wheels. The arrangement of the Civils Code is apparently a persistent relic of the days of over 100 years ago, when the steam engine was invented and developed, and when the word "engine" meant not only the actual steam engine, but the boiler and accessories as well. This point of view may have had some justification in, say, 1822, when 50 h.p. was regarded as a large size for an engine, and each engine as a rule had its own small separate boiler. In 1922, however, it is obviously out-of-date, because of the size and complexity of the modern steam generation plant, and because of the many uses of the steam, not only for engine and turbines of greatly different sizes and efficiencies, but also for numerous other processes, such as warming buildings, drying chambers, and heating liquids, in which the condensation loss in the pipe circuits of the factory alone is an important matter. It is for this same reason also that American engineers still persist in

talking of "boiler horse-power," an unscientific term which has died out in Great Britain years ago.

The only practical and scientific method is to regard the *generation* of steam as something entirely separate and independent from the *utilisation* of steam, whether for steam engines or for any other process, and in fact one of the reasons why this country is losing 20,000,000 tons of coal per annum on steam generation is because this very point is not understood. In the average factory, when some endeavour is made to keep a record of the figures for the fuel consumption, such attempts seldom rise above the conception of regarding the boiler and power plant together as merely one item. Thus, for example, a paper-mill expresses the figures of its performance as so many tons of paper, a brewery as so many standard forty-gallon barrels of beer, a flour-mill as so many sacks of flour, a bleach works as so many lumps of cloth, all per ton of coal.

The error of this method is that it is not detailed enough, and there is not only entire ignorance as to whether the cause of inefficiency lies in the generation of steam at the boiler plant, in condensation losses in the steam pipe circuits, or in poor engine performance, but the very many different and important functions of the boiler plant are carried out completely in the dark.

Yet the "Civils" Code helps to perpetuate this fundamental error by its method of regarding boiler plant and steam engine tests as something almost identical, so that they can be included in one Code.

In the International Code I suggest that boiler plant testing be regarded as something entirely separate, and as much independent of the testing of steam engines as it is of oil or gas engines, or any other source of motive power. A separate code for boiler testing also means greater simplicity, and would be a great help in convincing every one that efficient steam generation is an operation of vital importance, and worthy of the most careful attention.

2. **The Object of Boiler Plant Testing.**—The "Civils" Code gives the unfortunate impression that boiler plant testing is a costly and troublesome luxury to be undertaken only at rare intervals, and, secondly, that there are two kinds of tests, namely, to "obtain data for scientific purposes," and "commercial tests" to ascertain whether the guarantee of performance given by the maker has been fulfilled. It also speaks of "Comparative trials where the determination of efficiency is not the main object".

The four separate references to this point in the "Civils" Code are most confusing, and are given below (italics my own):—

(1) Page 5. "When the object of a boiler or engine trial is to *obtain data for scientific purposes* the losses should always be measured, because they afford a valuable check on the accuracy of a trial. Such measurements consist in taking the temperature of the flue gases and analysing them, weighing the ash, measuring the loss of heat by radiation, etc. Though desirable, *they are not essential in a large* majority of trials, when those observations only are recorded which are necessary to ascertain whether the guarantee of performance given by the maker has been fulfilled. For such trials a shortened tabular statement has been provided under the heading '*Commercial Trials*' [1]."

The note [1] refers the reader to page 23, which reads as follows, at the bottom of the page:—

(2) Page 23. "Notes: (1) The lines printed in italics relate to data which may be omitted where a shorter form of Report for general purposes is desired (see Committee's Report, p. 4)."

On turning back again to page 4 we find:—

(3) Page 4. "As regards the last item, the *original forms intended for scientific purposes*, in which it is necessary to measure the losses, have been retained as far as boilers and reciprocating engines are concerned, but abridged forms have also been drawn up for more general use, as described in note 1 on page 23."

Finally, on page 58 is stated:—

(4) Page 58. "If the object of the trial is *to ascertain, for*

scientific purposes, the rate of evaporation for a constant rate of coal consumption. . . ."

A general impression also, on reading through the "Civils" Code, is that boiler plant testing is an extremely complicated and difficult operation, which involves a knowledge of chemistry and mathematics quite beyond the ordinary engineer, and which can only be carried out by the University graduate. These ideas are quite erroneous. Boiler plant tests must be regarded as of such vital importance that they must be carried out regularly as part of the routine of the daily running of a boiler plant, and there is nothing mysterious or difficult about them. In the International Code I would suggest one standard code for all boiler tests, and to do away with any idea of distinction between "Scientific" and "Commercial" Tests, which only causes confusion and which, in any case, is wrong in principle. I would draw up the Code on such lines that the main object of boiler plant testing is to keep boiler plants at the maximum efficiency every week, all the year round, and such a Code would be flexible in the sense that it would include all special tests, such as the investigation of a particular quality of fuel, of any plant, machinery, or appliance installed on the plant, and the working of the plant under different conditions of load.

In short, boiler plant testing must be regarded as a thoroughly practical proposition which is necessary for the strictly utilitarian purpose of saving money.

3. **Duration of Test.**—The duration of the test is a matter of the greatest importance in determining the true performance of a boiler plant, and the "Civils" Code is very vague on this point. All the definite instructions it gives are as follows (p. 9):—

"The approximate duration of the trial should be fixed before commencing it and should be a multiple of the period elapsing between the times of cleaning the fires; it should never be less than three hours, and should be as long as possible in order to eliminate error in the measurement of the thickness of the fuel."

It must be obvious that the test has got to be of sufficient duration to allow of the elimination of errors. Thus, I presume even the Civil Engineers' Committee would agree that, for example, the figures of a test of one hour's duration would be worthless as a true indication of the average working of a boiler plant. To allow an official test of only three hours is absolutely ridiculous, as every one must know who has had much practical experience of boiler plant testing, and no reliance whatever could be placed upon such a test.

What is meant by the statement that "the duration of the trial should be fixed before commencing it" and "should be a multiple of the period elapsing between the time of cleaning out," I am at a loss to understand.

The American "Mechanicals" Code is infinitely more sensible, definite and practical on this point, as follows:—

Page 43. "44. The duration of tests to determine the efficiency of a hand-fired boiler should be at least ten consecutive hours. In case the rate of combustion is less than 25 lbs. per sq. ft. of grate per hour, the tests should be continued for such a time as may be required to burn a total of at least 250 lbs. of coal per sq. ft. of grate. Tests of longer duration than ten hours are advisable in order to obtain greater accuracy.

"45. In the case of a boiler using a mechanical stoker, the duration, where practicable, should be at least twenty-four hours. If the stoker is of a type that permits the quantity and condition of the fuel bed at beginning and end of the test to be accurately estimated, the duration may be reduced to ten hours, or such time as may be required to burn the above noted total of 250 lbs. per sq. ft.

"In commercial tests, where the service requires continuous operation night and day, with frequent shifts of firemen, the duration of the test, whether the boilers are hand-fired or stoker-fired, should be at least twenty-four hours. Likewise in commercial tests, either of a single boiler or of a plant of several boilers, which operate regularly a certain number of hours and during the balance of the day the fires are banked, the duration should not be less than twenty-four hours.

"The duration of tests to determine the maximum evaporative capacity of a boiler, without determining the efficiency, should not be less than three hours."

It will be noted that the American Code insists on at least ten consecutive hours, and that the three hours allowed by the "Civils" Code for the complete test is in the American Code only allowed for the comparatively unimportant operation of determining the maximum evaporative capacity of the plant, quite irrespective of the efficiency.

Surely the common-sense guide to the duration of the test is the actual practical working conditions of the given boiler plant. If, for example, the boiler plant starts up at 8 a.m., runs full output until 12 midday, partially shuts down for the dinner hour until 1 o'clock, and then runs full output again to 5 o'clock, the only proper course is to run the test right through for nine hours, that is from 8 a.m. to 5 p.m., including the partial stop in the dinner hour. In a colliery, for example, or under colliery conditions on an experimental plant, the maximum "winding period" may be from 6 a.m. to 2 p.m., in which case the test would be carried out for this period.

Certain industries, such as flour-mills and paper-mills, as a rule, run right through twenty-four hours a day on steady load for six days, in which case, of course, the test can be carried out at any time.

I would propose that in the International Code no test should be regarded as official if of less duration than eight hours, and in every case longer than this, or the full working day or shift, is much preferable. In the few cases where the complete working day or shift is less than eight hours, I would allow the lesser time, but would attach little importance as a rule to any test of less than six hours' duration.

It would not be possible to include the American figures of ten hours and twenty-four hours in an International Code, because, for example, in this country the average working day is now only eight hours.

On this point of the duration of the test a second very serious matter for criticism, in both the "Civils" Code and the American "Mechanicals" Code, is the total omission of all reference to the figures for the performance of the boiler plant

when starting and stopping, when banked up, and on light load at night and during the week-end. Most boiler plants do not suddenly start up at full load, run for a test period, and then suddenly shut down again. The usual practice is to run on intermittent loads during the night, for keeping buildings warm and perhaps working the factory at much reduced load; and also for the boiler plant to remain banked up under pressure during the week-end, if only to be able to work the pumps in case of fire.

Speaking in averages, anything from 10 to 30 per cent. of the annual coal bill is usually absorbed in this way, and a test carried out in the spirit of both the Codes only applies therefore to the 70 to 79 per cent. of the coal burnt during ordinary working hours.

I found out very soon, by practical experience, that it is necessary to carry out a long check test to include the essential elements of the day's test, namely, the amount of water evaporated and coal burnt, together with the heating value of the coal, and consequently out of the 400 tests, 365 tests have a long check test of one complete week in addition. In the International Code, therefore, I would suggest a long check test of a complete week of 168 hours, that is, including the full week-end, and the combination of the two tests, namely, a day test of not less than eight hours, and a full week's test, will give, in my opinion, a much more satisfactory test of a boiler plant both from a practical as well as from an academic and scientific point of view.

In the 400 tests, thirty-five plants were tested during the day only, either because it was impossible to carry out a week's check test without a great deal of trouble, or because of the express wish of the client. In the remaining 365 tests, 185 plants gave a slightly inferior result as compared with the day's test, and 180 tests showed a somewhat better result. There is always some loss by cooling during the week-end, but this is often counter-balanced by the fact that a boiler

plant may have been forced during the day, so that the efficiency is less than at night when on easy load.

4. **Sampling and Analysis of the Fuel.**—Both Codes give, on the whole, very clear instructions as to the sampling of the fuel, and the necessity of taking proper average samples. There is no doubt that many boiler trials are rendered of little value through defective sampling, and it is somewhat difficult to lay down definite rules for this operation, which is, after all, a matter of common sense. I think, however, the instructions in the Codes would be improved if they insisted that two entirely independent samples of the fuel are taken during the trial. Thus, if samples are taken from each barrow, or bag, or, say, at intervals of half an hour from railway waggons or overhead bunkers, it is better to keep two separate samples (A and B) and to place them separately in two receptacles (A and B) during the trial. At the end of the trial the two large samples are then mixed, broken up, quartered, etc., and small portions sent for analysis in separate sealed tins (A and B). These are then analysed separately and the results given are an average of the two separate analyses. I have found this in practice a very satisfactory method, and would suggest, therefore, that this be embodied in the International Code, with the proviso that it is of course impossible to take too many samples, and these instructions be regarded as the minimum requirements.

On the question of the analysis of the fuel, and the gross and net heating value, neither Code is very lucid. The "Civils" Code decides that the efficiency calculations shall be based on a calculated lower or net heating value, whilst the American "Mechanicals" Code takes the simple or gross heating value of the dried coal as determined in the oxygen bomb calorimeter.

It is agreed in the first place by all concerned that the calorimeter to be used for the determination of the gross heating value of a fuel shall be of the oxygen bomb type, in which a weighed amount of fuel is burnt in a known weight

of water at a known temperature. The rise in temperature of the surrounding water, as recorded by a delicate thermometer, will then give an absolutely accurate measurement of the amount of heat in the fuel, since the combustion is complete, as it is in high pressure oxygen, and no heat can be lost, because it takes place in a sealed bomb under the water.

The "Civils" Code mentions on page 37, in the Introduction, Appendix I., under the "List of Apparatus required for a Boiler Test," item No. 13, "*A Barrus or other Calorimeter*".

So far as I am aware no such instrument has ever been in general use in Great Britain, the three best-known makes of oxygen bomb calorimeter in this country being the "Mahler-Donkin," the "Mahler-Cooke" and the "Berthelot-Mahler," all of which are most efficient instruments.

The "Civils" Code would seem to imply that it regards the "Barrus" calorimeter (apparently an American instrument) as the best, but I would suggest that in the International Code any approved make of oxygen bomb calorimeter would be allowed. The American "Mechanicals" Code does not mention the Barrus calorimeter but recommends (p. 19) the Mahler type.

The heating value so determined in a bomb calorimeter is termed the "gross" or higher heating value. This value, however, is not the same as the actual heating value available for a boiler from the combustion of the fuel in the fire, firstly because of the natural moisture, and, secondly, because of the percentage of hydrogen, in the coal. All coal contains such natural moisture, which may vary from, say, 2 to 8 per cent., and if the coal is completely dried, it at once re-absorbs this moisture from the air. Further, coal delivered to a boiler plant may contain up to 25 per cent. moisture if it has been washed, or exposed to the weather. Also dry coal contains hydrogen as one of its normal constituents, the amount usually varying from 2 to 4 per cent.

J. S. S. Brame ("Fuel, Solid, Liquid and Gaseous," 1919)

gives the ultimate composition of various coals as follows, that is, without taking into account ash and moisture:—

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Splint coal (Fife)	82·0	5·00	12·80
Gas coal (Durham)	85·0	5·50	8·20
Coking coal	87·3	5·05	6·90
Smokeless coal (Welsh)	91·3	4·05	3·90
Anthracite (Scotch)	91·1	3·50	4·65
,, (Welsh)	91·0	3·90	4·28

During the combustion of coal the hydrogen burns to water, and consequently in a bomb calorimeter the natural moisture of the coal, and the moisture formed by the burning of the hydrogen, is first volatilised to steam, which is enclosed in the bomb and cannot escape, and then, because of the cooling water outside, is condensed to water again inside the bomb, and gives up all its latent heat, which is therefore included in the gross heating value of the coal.

For example, take a coal of 11,500 B.Th.U. gross heating value as determined in the bomb calorimeter, and having 5 per cent. of natural moisture, and 4·0 per cent. of hydrogen, calculated to the coal as fired, and exclusive of the hydrogen in the moisture.

If the water in the calorimeter jacket outside the bomb is 60° F., so that the condensed water from the combustion of the coal inside the bomb will also be cooled to 60° F., the heat given up in the bomb by 1 lb. of water, in condensing from steam, would be 970·7 B.Th.U., the latent heat in 1 lb. of steam, and roughly 152·0 B.Th.U. in cooling from water at 212° to 60° F., that is, a total of 1122·7 B.Th.U.

Since the percentage of moisture in the coal is 5, in 1 lb. of coal which has a gross heating value as determined by the bomb calorimeter of 11,500 B.Th.U. per lb., 56·1 B.Th.U. (5 per cent of 1122·7) will be really due to the natural moisture of the coal, being retained in the coal and cooled to 60° F.

If we assume, however, that in a boiler furnace all the water in the coal is vaporised, and passes right out of the plant to the chimney base as steam in the flue gases, and the temperature of the coal when thrown into the fire is 60° F. (and therefore the 5 per cent. water in the coal is also 60° F.) and the temperature of the exit gases is, say, 350° F., the loss of heat per lb. of water in the coal will be 154·6 units, to heat the water in the coal from 60° to 212° F. 970·7 units to convert the water at 212° F. to steam at 212° F. (latent heat), and 62 units to heat the steam to 350° F. (the average temperature of the exit gases), taking the specific heat of steam at atmospheric pressure as 0·45, making thus a total of 1187·3 B.Th.U.

Since the percentage of water in the coal is 5, the heat lost per lb. of coal is therefore 59·36 (5 per cent. of 1187·3). The real net heating value of the coal, for these particular conditions, taking into account the moisture only, is therefore 11,500 - 59·36 = 11,440·6 B.Th.U.

In the same way the 4 per cent. of hydrogen in the coal burns and forms an amount of water equivalent to 35·76 per cent. of the weight of the coal (1 part by weight of hydrogen unites with 7·94 parts of oxygen to give 8·94 parts of water), and, as before, this escapes up the chimney as steam at 350° F. The heat lost is therefore 424·6 B.Th.U. (35·76 per cent. of 1187·3).

Although the gross heating value by means of a bomb calorimeter of such a coal is 11,500 B.Th.U., the actual net heating value under the given practical conditions will only be 11,500 - 59·3 - 424·6, that is, 11,016·2 B.Th.U., certainly a very serious difference.

It is obvious, however, that in arriving at a lower heating value of the coal, it is not possible to include the various temperatures of the exit gases on different boiler plants. If this was done, the higher the exit gases (and therefore the more inefficient the plant) the lower would be the calculated lower heating value of the coal, which would favour the plant with

the highest exit temperature, and, further, the lower heating value of any fuel could not be given until the temperature of the exit gases of the corresponding boiler plant was known. The only possible way, therefore, is to assume that the temperature of the coal is 60° F. and to deduct for each 1 lb. of water in the coal, say, 154·6 B.Th.U. to heat the water in the fires from 60° to 212° F. and 970·7 B.Th.U. to convert 1 lb. of water at 212° F. into steam at 212° F., that is, a total of, 1125·3 B.Th.U. The reason for taking 212° F. is that this is in practice the theoretically perfect exit temperature of a boiler plant, because if the temperature was 211° F. all the water in the flue gases, sometimes as much as 50 per cent. of the weight of the coal, would condense in the flues and render the plant unworkable. There is a further complication with regard to this question of the higher and lower heating value. It does not necessarily follow that all the water from the coal actually does escape to the chimney as steam, carrying all the latent and other heat. It is true that the temperature in the chimney base is hardly ever less than 300° to 350° F. and certainly nothing approaching 212° F., so that theoretically all the moisture should pass away as steam, but it is almost certain that in exposed portions of the plant, such as the brickwork of the economiser, underneath the front of the boiler where cold air is almost always entering, and so on, some portion of the moisture is condensed locally. We know, for example, that this is often the case with the economiser pipes, giving what is known as "sweating," which causes corrosion. Whenever this local condensation takes place, the latent heat is given up to the plant, and does not pass away. If this is granted, it is not absolutely correct to calculate the net heating value of the fuel as is done in the "Civils" Code, since we have an indeterminate and unknown factor which would make the real practical heating value of the coal somewhere between the ordinary gross (higher) and net (lower) figures, although of course the usual calculated net figure would be much more accurate than the gross figure.

The chief objection, however, to the method of using the calculated net or lower heating value is the necessity of carrying out every time the complicated and troublesome organic analysis of the percentage of hydrogen in the coal.

As already emphasised, we have to look at this boiler plant testing from a practical point of view, as something which must be done regularly as part of the routine of the plant.

I would suggest, therefore, in the International Code to abandon the idea of using the calculated net or lower heating value, and to substitute for it the higher heating value as obtained in the oxygen bomb calorimeter from the dried sample of fuel, and then calculated back to the percentage of moisture. That is to say, the percentage of moisture in the coal would be first determined, and the heating value of the dried coal obtained by means of the bomb calorimeter.

Thus, to take an actual case, a given water-tube boiler evaporated 310,000 lbs. of water in 8·00 hours, the temperature of the water being 110° F. before the economisers and 275·0° F. after. The boiler pressure was 200 lbs. (gauge) and the superheat temperature 645° F. (specific heat calculated as 0·541). The amount of coal burnt was 53,850 lbs. The coal on analysis was found to contain 11·58 per cent. of moisture, and the actual gross heating value of the dried coal was 10,823 B.Th.U. per lb., whilst the percentage of hydrogen in the dried coal was 3·75 (determined specially for this example). The corresponding simple calculated gross heating value for the coal as fired would be 9570 B.Th.U. (10,823 in the dry and 9570 in the damp, with 11·58 per cent. of water). The calculated lower heating value, according to the method I should propose, would be 9439·7 B.Th.U., that is, the loss by heating 11·58 per cent. of water in the coal from 60° to 212° F. ($= 17·90$ B.Th.U. being, as already seen, $\frac{11·58 \times 154·6}{100}$) and converting it into steam at 212° F. ($= 112·41$ being, as

before, $11\cdot58 \times \frac{970\cdot7}{100}$), making a total of 130·3 B.Th.U. to be deducted (9570 − 130·3 = 9439·7). The calculated lower heating value, including the organic hydrogen, would be 9106·9 B.Th.U. The percentage of organic hydrogen in the dried coal being 3·75, this in the damp coal (11·58 per cent. water) corresponds to 3·32 per cent. As already seen, 3·32 per cent. hydrogen produces 3·32 × 8·94 = 29·68 water, and this on heating from 60° to 212° F. and converted to steam at 212° F. will absorb 333·9 B.Th.U., so that, added to 130·3 B.Th.U., due to the moisture, the total deduction will be 464·2 B.Th.U., that is, 9571 − 464·2 = 9105·8 B.Th.U. Further, the gross heating value, as determined by the bomb calorimeter, of the damp coal as fired was found to be 9521 B.Th.U. We have therefore three distinct heating values possible for this coal, namely, 9521 B.Th.U., the gross value in the bomb as fired, 9439·7, the calculated net value, not including the organic hydrogen but including the water and assuming an exit temperature of 212° F. on the plant, and 9105·8, including both the water and the hydrogen, and assuming as before an exit temperature of 212° F.

The objection to the method suggested, that is, ignoring the organic hydrogen, is of course that this organic hydrogen content may vary from almost zero in the case of coke, up to as high as 4 to 5 per cent. in very bituminous coal. I have drawn a curve (Fig. 1) showing the number of B.Th.U. to be deducted for any corresponding percentage of hydrogen, and as seen, the figure is practically 100 B.Th.U. for every 1·0 per cent. organic hydrogen in the coal. By the method suggested, therefore, the larger the percentage of hydrogen in a coal, the greater is the error in favour of the boiler plant, so that with any given plant the best calculated results would be shown by using a bituminous coal, and the worst by using anthracite, and above all, coke. We are faced, however, with the difficulty that to obtain the greatest accuracy on this point a greatly increased amount of trouble is necessary, and, in my opinion, this is not justified from a practical point of view.

Another suggestion, however, would be to take the percentage of hydrogen in all coals as either the arbitrary figure of 3 per cent., or perhaps 0·03 per cent. of the heating value as determined in the dried coal, and calculated for moisture only. In the former case 300 B.Th.U. would then be subtracted, and in the latter case, with a heating value of

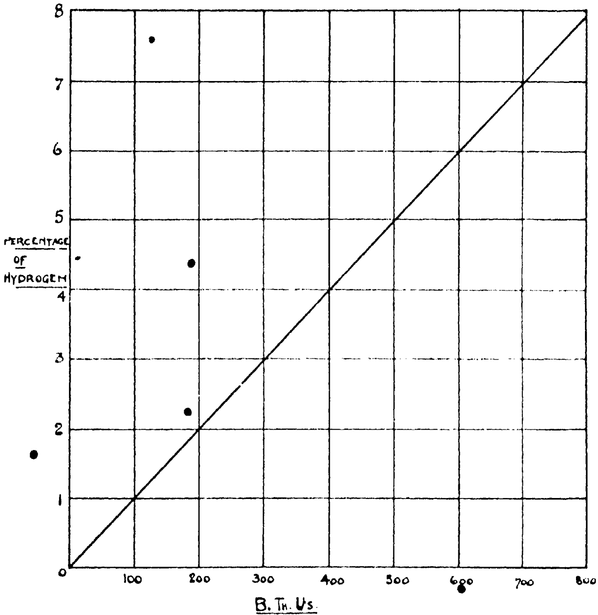

FIG. 1.—Curve showing the B.Th.Us. to be deducted for a corresponding percentage of hydrogen calculated in the coal as fired.

9439·7 B.Th.U. the figure would be 9439·7 × 0·03 = 283·19. This, subtracted from 9439·7, would give 9156·5 as the final heating value. Some such arrangement would reduce the practical error to a negligible quantity, and would probably be as accurate as the present complicated method involving the determination of hydrogen.

In order to show the different efficiency figures obtained by these various heating values, the actual figures of the test results already given, work out as follows :—

	B.Th.U. Gross Actually in the Coal as Fired, 9521 B.Th.U.	B.Th.U. in Dry Coal and Calculated for Moisture, 9139·7 B.Th.U.	B.Th.U. in Dry Coal and Calculated for Moisture and Organic Hydrogen, 9105·8 B.Th.U.	B.Th.U. in Dry Coal and Calculated for Moisture and 0·03 × Heat Value in Lieu of Hydrogen, 9166·5 B.Th.U.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Net working efficiency of plant after deducting 1·5 per cent. auxiliary steam used on the plant . . .	73·10	75·76	78·54	78·12
Heat absorbed by the boiler .	57·70	58·20	60·34	60·02
Heat absorbed by the economiser	10·15	10·23	10·60	10·55
Heat absorbed by the superheater	8·39	8·48	8·80	8·75

There is, therefore, a difference of about 2½ to 3 per cent. in the efficiency, according as to whether organic hydrogen is included or not, always remembering that in the latter case we assume the coal to be 60° F. and all the moisture from the coal escapes from the boiler plant as steam at 212° F.

In view of the great confusion existing on this point, and the trouble necessary to determine the organic hydrogen, the 400 tests have, as already stated, been calculated according to the more usual practice on the gross heating value of the fuels as determined by the bomb calorimeter. In proposing now to use a calculated lower figure, ignoring the organic hydrogen, it has always to be remembered that any International Code gives the minimum data necessary. There is nothing to prevent any given test, by arrangement, including the organic hydrogen as supplementary.

5. **Flue Gas Analysis.**—I am of the opinion that the methods suggested by both Codes for flue gas analysis are out-of-date. They do not explain at all clearly what is the object of flue gas analysis, and confine their attention almost

entirely to the old-fashioned method of hand analysis, and even then the methods described are often not practical.

With regard to the theory of gas analysis: Air contains 21 per cent. of oxygen by volume, and if coal (or other fuel) was pure carbon, and just the right amount of air was used, then the flue gases, that is, the air after passing through the fires, would contain 21 per cent. carbon dioxide (CO_2). Since coal is not pure carbon, and, as fired, may contain only from 60 to 90 per cent., whilst at the same time hydrogen is present to the extent of say 2 to 4 per cent., which burns to water, it is obvious that 21 per cent. CO_2 cannot be obtained, even if the combustion is perfect. With anthracite or coke, say 18 to 19½ per cent. can be regarded as a theoretical figure, and for ordinary semi-bituminous steam coal say 17 to 18 per cent. If less than these figures for CO_2 are obtained, it may indicate that excess air is passing through the furnace, that is to say, there is a drop in efficiency due to this excess air carrying heat away from the plant. We have also to consider the case when less air than the theoretical is passing through the fires. In this case part of the carbon of the fuel only burns to CO (carbon monoxide) because there is not sufficient oxygen to complete the combustion to CO_2, and the flue gases contain free CO along with a high percentage of CO_2. This represents a very serious loss in efficiency because CO is an inflammable gas, and 1 lb. of carbon burnt to CO only gives 4400 B.Th.U. instead of 14,544 B.Th.U., when properly burnt to CO_2.

Also, it is possible to have CO, CO_2 and excess air present in a flue gas at the same time, because in one part of the furnace there may be an excess of air and in another part a deficiency. Generally, however, a low CO_2 percentage means no CO, and CO is usually present to an appreciable amount only when there is a high CO_2 percentage. It may be added that flue gases may contain also minute amounts of methane (CH_4), hydrogen (H_2) and sulphur dioxide (SO_2), but these are of no practical importance.

It will be obvious, therefore, that the analysis of the flue gas is a vital part, not only of the testing of a boiler plant, but also of its daily running as well, and if the flue gases are not analysed regularly it is not possible to keep the plant up to the highest efficiency by controlling the firing.

The principle of flue gas analysis is to take a measured volume of the gas, say 100 c.c., at normal temperature and pressure, and to pass it through 20 to 25 per cent. caustic potash solution. This absorbs the CO_2 (and any traces of sulphur dioxide or other acid gases), and the reduction in volume gives the percentage of CO_2, *i.e.*, if 90 c.c. of gas is left, there is 10 per cent. of CO_2. The 90 c.c. of gas is then passed through $7\frac{1}{2}$ per cent. pyrogallic acid in 25 per cent. caustic potash solution (or over phosphorus), which absorbs the oxygen, and after the further reduction in volume has been read off, the remaining gas is passed into a solution of 12 per cent. cuprous chloride in 25 per cent. hydrochloric acid, which absorbs the CO.

Such an analysis is carried out by hand in an "Orsat" or similar apparatus, but the process is very tedious and takes twenty to thirty minutes for one analysis, and it is not surprising, therefore, that many attempts have been made to invent a continuous gas analysing machine. The ideal for boiler testing and control would be a machine that would give a record every few minutes of the percentage of CO_2 and CO and other escaping inflammable gas. Only within the last few months has such a machine been perfected, after years of experimenting, by the Svenska Aktiebolaget "Mono" Co. of Stockholm, and is now on the American and British markets under the name of the "Duplex Mono" (automatic gas analysing machine).

This machine is a revolution in flue gas analysis, as it takes automatically a sample of flue gas at the rate of twenty times an hour, determines the percentage of CO_2 in every alternate sample and writes down the result on a chart together with the time of the analysis, and in the other alternate sample burns first in the machine the unburnt gas to CO_2, and then determines the

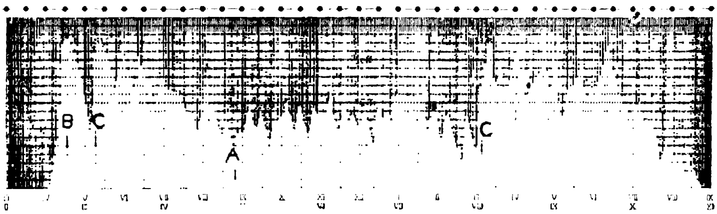

FIG. 2.—Record with "Duplex Mono" ordinary working, showing varying CO_2, and much CO and unburnt gases at periods commencing B and C.

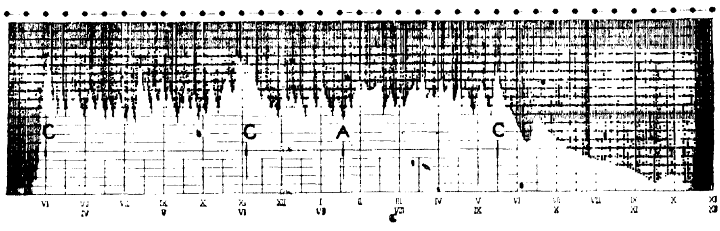

FIG. 3. Record with "Duplex Mono" showing ideal working with high CO_2 and no CO, except at one short half-hour period.

[*To face p.* 67.

CO_2, the increase being due to unburnt gas. It is difficult to explain the operation of the "Duplex Mono" in a few words, but the machine works by the rise and fall of mercury driven by water power or compressed air, and the samples of flue gas are automatically and alternately diverted direct to the caustic potash solution for the determination of CO_2 and then through a small electric heated furnace containing copper oxide on the top of the machine in which all unburnt gas is consumed, and afterwards to the caustic potash. Specimen charts are shown in Figs. 2 and 3. In Fig. 2, following the points B and C, there is a large amount of unburnt gas, since the records of each alternate analysis are far apart. If one series of samples shows about 10 per cent. CO_2 and the alternate series 12 per cent. it is a clear indication of unburnt gas, since the CO has been burnt to CO_2 in the electric furnace and increased the percentage of CO_2. The ideal is shown in Fig. 3 where the average CO_2 for many hours is about 11 per cent., with only a little CO for half an hour.

The "Duplex Mono" is illustrated in Figs. 4, 5, 6, and a previous machine for the determination of CO and unburnt gases only in Fig. 7. The original "Mono" CO_2 Recorder only is identical with the "Duplex Mono" but without the mechanism for CO determination.

In this way, for the first time, we can obtain on a boiler plant the "critical point of efficient combustion," that is, the maximum CO_2 with absence of CO and unburnt gases.

Ordinary Combustion Recorders, that is, continuous gas analysing machines for determining the percentage of CO_2 only, have been known for many years. Such machines will also give on the average twenty analyses per hour, writing down the result, together with the time of analysis, upon a chart, and are indispensable for modern boiler plant testing and control.

For some extraordinary reason it has always been the custom for most recognised authorities on boiler plant testing to disparage the CO_2 Recorder.

Thus the American "Mechanicals" Code says (p. 19):—

"Instruments known as CO_2 Recorders are useful, if their accuracy is established."

and the whole of the rest of the space (pp. 19, 46, and 172-174) devoted to flue gas analysis is taken up with a detailed description of the "Orsat" and "Hempel" hand apparatus. The only reference in the "Civils" Code is as follows (p. 70):—

"If the percentage of carbon dioxide alone is required, the 'Ados' or any other good recording instrument may be advantageously used, provided that it is checked before and during the trial."

It may be stated that the "Ados," a German machine, which is obviously regarded by the "Civils" Code as the best, is so completely antiquated that the last instrument was sold in this country fifteen years ago (that is in 1907). It belonged to the very early type of Combustion Recorder worked by means of a large gasometer actuated by the chimney draught, and would be regarded to-day as a curiosity.

The "Civils" Committee seem to be totally unaware that there are on the market a large number of CO_2 Recorders, almost any one of which will give continuous and accurate records of the percentage of CO_2.

When the "Civils" Code was revised in 1913, the following instruments were on sale in this country (as they are to-day), either by the British manufacturers or their agents, or by British agents of foreign manufacturers:—

"Albion" (British)
"Auto" (British)
"Bimeter" (British)
"Mono" (Swedish)
"Sarco" (British)
"Simmance-Abady" (British)
"Ward" (British)

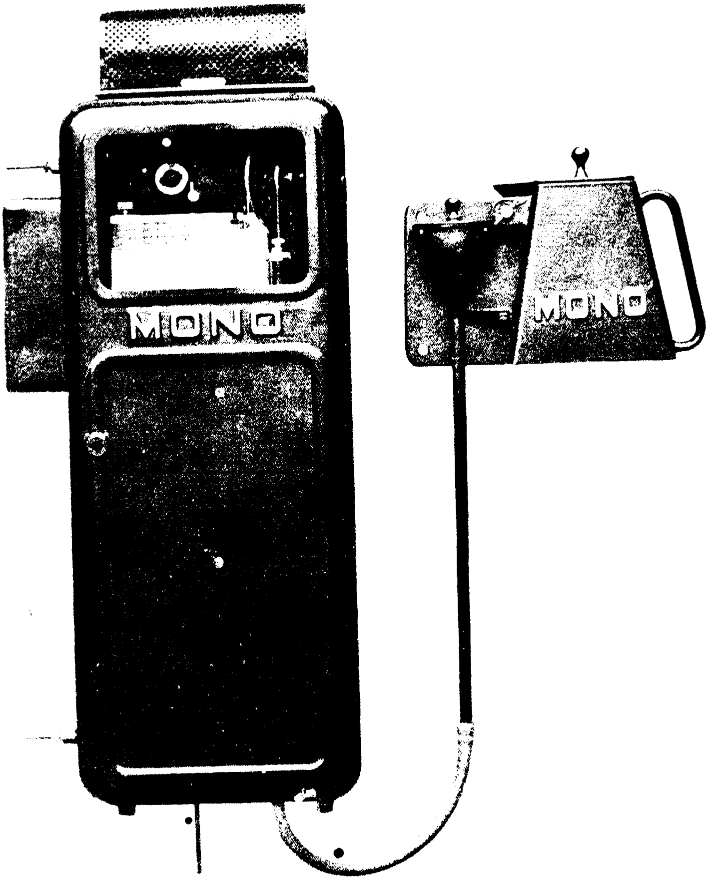

FIG. 4.—"Duplex Mono," closed as when working normally in the firehole.

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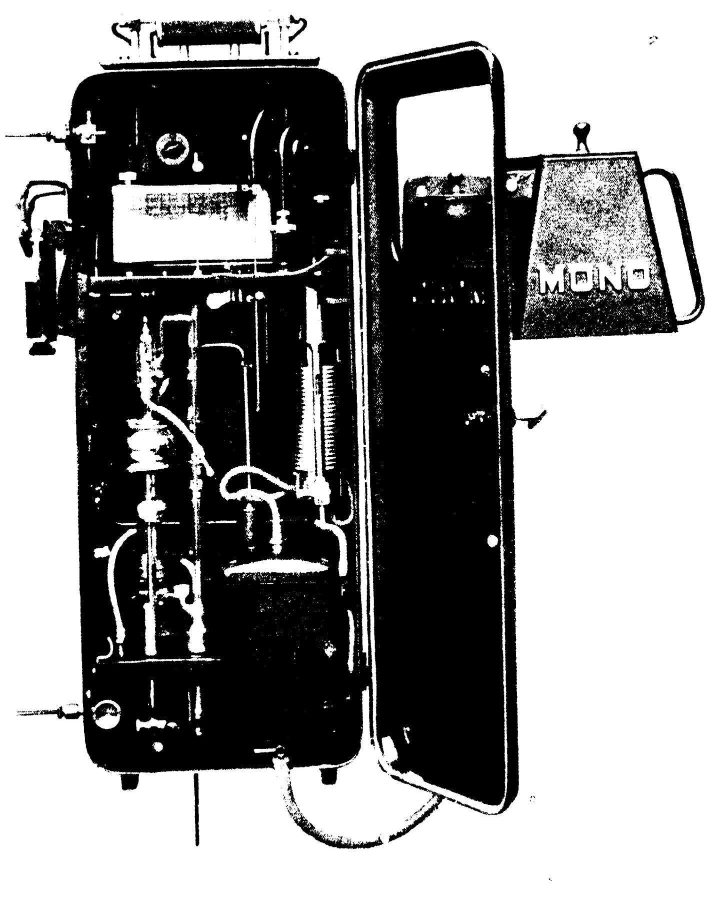

FIG. 5.—"Duplex Mono," front view, with door open.

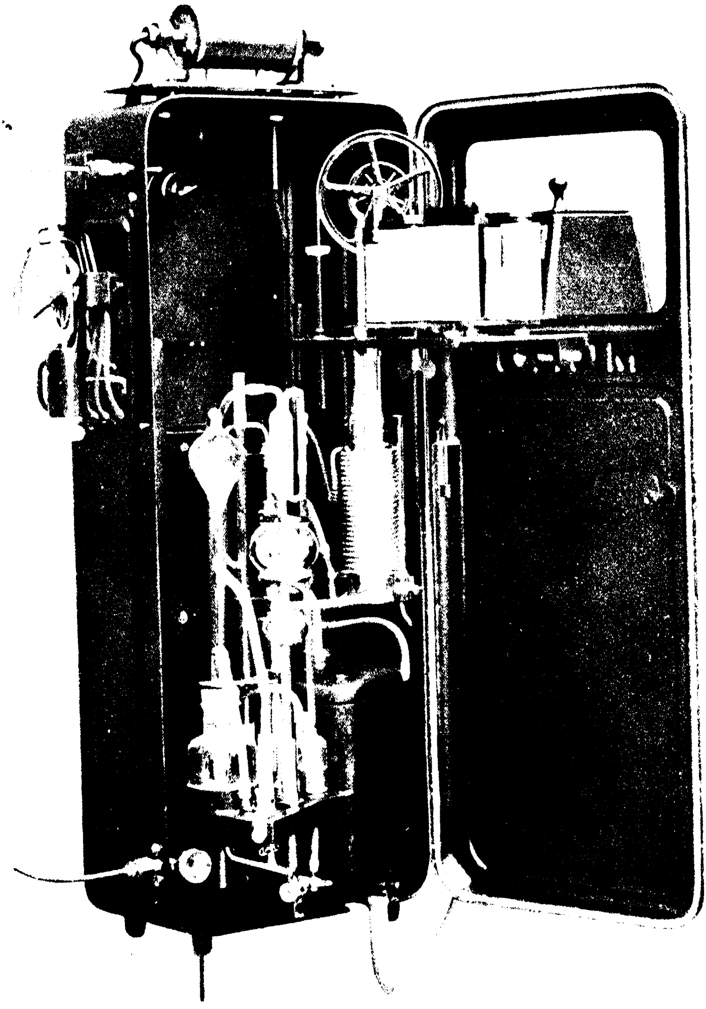

Fig. 6.—"Duplex Mono" with clock and other mechanism exposed whilst the machine is actually running.

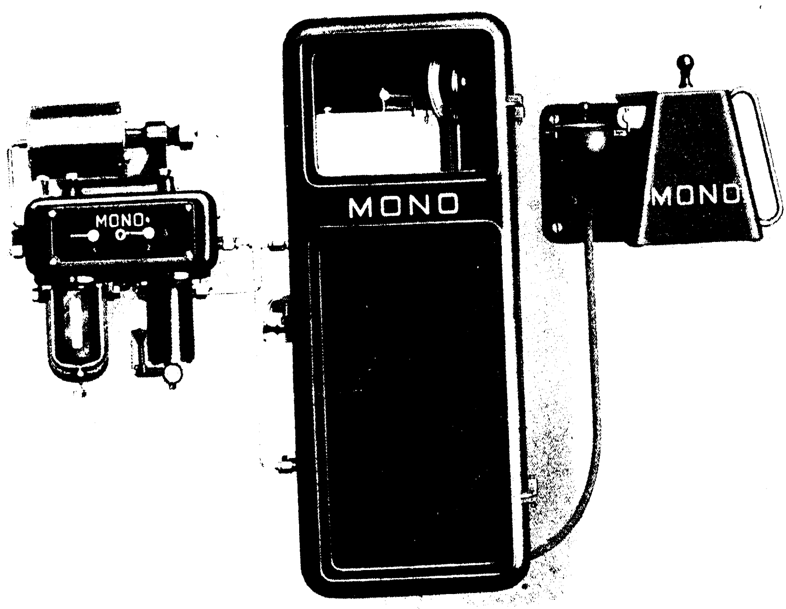

Fig. 7.—Original "Mono" automatic gas analysing machine for CO and unburnt gases only.

and there are now the following additional instruments put on the British market since 1913:—

"Cambridge Electrical" (British)
"Hays" (American)
"W.R." Combustion Indicator (British).

There must be almost an equal number of different makes of CO_2 Recorders on the American market, and there are also a number of continental machines, chiefly French, German and Dutch. To insinuate that all these instruments, most of which have been on the market for years, and in many cases tested and certified correct by the National Physical Laboratory, cannot be used for determining accurately the percentage of CO_2 on a boiler test is, in my opinion, not only ridiculous, but grossly unfair to most makers of CO_2 Recorders.

It might be thought therefore that, as far as the "Civils" Code is concerned, the section relating to Flue Gas Analyses was originally drawn up in the years 1897-1902, when there may have been a good excuse for ignoring the CO_2 Recorder, and that the Revision Committee of 1913 had practically left the original instructions alone, although they were by this time hopelessly out-of-date. In spite of this, however, it is explicitly stated in the introductory letter (p. 4) that one of the sections revised was the sampling and analysis of the flue gases.

The "Civils" Code, as seems to be usual when any modern appliance is considered, throws doubt on the accuracy of all CO_2 Recorders, and states they must be checked, not only before the trial, but during it as well (!). It may be remarked that to test the accuracy of most CO_2 Recorders, all that is necessary is to let the instrument run on air for a few minutes to ensure that the chart record is exactly 0·0 per cent. CO_2. To talk of testing a CO_2 Recorder "during" the trial, that is every few hours, is childish, and one is compelled to come to the conclusion that most of the members of the

"Civils" Committee have had little or no experience with CO_2 Recorders.

I would like to guarantee that the results given by the average CO_2 Recorder are far less liable to error than the clumsy methods of hand analysis recommended by the "Civils" Code, apart from the fact that the average CO_2 Recorder will give twenty analyses in the same time that it takes to carry out three or four analyses by hand.

In the International Code I would make it compulsory to use a CO_2 Recorder working at a proper speed of say fifteen analyses per hour, but preferably twenty analyses, so that on the day's trial at least 150 CO_2 determinations will be carried out. Further, I would suggest that the CO_2 Recorder be worked day and night on the plant for the whole week's check test, say six or seven hours in turn, taking flue gas from essential portions, such as the downtake or side flue of "Lancashire" boilers, or entrance to the main flue of each water-tube boiler, the main flue, chimney base, etc., so that during the whole test about 2500 analyses of CO_2 would have been carried out. There is very little trouble in obtaining results like this with a CO_2 Recorder, and in fact it is much less trouble to get 500 analyses with a recorder than to carry out ten analyses by hand.

I have used CO_2 Recorders on every one of the tests of 400 boiler plants during the last twelve years or so, and it is possible to take a CO_2 Recorder equipment on to a boiler plant and have it recording the percentage of CO_2 on a chart at the rate of twenty analyses per hour in fifteen minutes from the time of arrival on the plant. For convenience, it is best to have the instruments taken out of their original iron cases and installed in special wooden cases, so that they can easily be carried about and hung up on the wall close to the boilers. Most CO_2 Recorders use a trickle of water (3 to 5 gallons per hour) to drive them, and the easiest method is to place on the top of the recorder a small galvanised iron cistern, specially made

to fit, and holding about 2 gallons of water. All that is needed to work the instrument is a bucket of water, the tank being filled, the water allowed to work the CO_2 Recorder through a tap, and run down into the bucket underneath, when it can be returned to the tank about every half-hour. At the points of analysis ½-in. W.I. pipes are inserted in the flues, and provided with rubber corks through which a piece of glass tube is inserted. The CO_2 Recorder is then hung up near the chief points, and connected to the glass tube by means of a thick india-rubber tube. The other end of the CO_2 Recorder is connected in the same way to another piece of ½-in. W.I. pipe inserted in the chimney base or adjacent main flue. A convenient way to do this is to take several lengths of ½-in. W.I. pipe and lay them on the floor temporarily for the test. By this arrangement a continuous circulation of flue gas is ensured, that is to say, if, for example, the point of analysis is the side flues of a "Lancashire" boiler, the draught in the chimney base pulls a continual current of flue gas from the side flues through the CO_2 Recorder, and there is no inaccuracy due to "lag" in the pipes.

As already stated, this question of CO_2 is also of the greatest importance in the regular working of a boiler plant, and it is most unfortunate, to say the least of it, that the present standard Boiler Testing Codes should not only be out-of-date in this respect, but should also disparage the CO_2 Recorder in the most unjustifiable manner.

In the 400 tests since 1908, with which I have been associated, there is included approximately 400,000 analyses of CO_2 by means of CO_2 Recorders, and the average figures of CO_2 for all these tests is only 7·5 per cent., and I should estimate that at least 90 per cent. of the boiler plants of Great Britain are unprovided with CO_2 Recorders in running order.

The figures for the 400 plants are divided as follows :—

Percentage of CO_2.	No. of Plants.	Corresponding Figure Expressed as a Percentage.
12 per cent. and over	10	2·5
11 ,, ,, ,, ,, ...	10	2·5
10 ,, ,, ,, ,, ...	39	9·9
9 ,, ,, ,, ,, ...	48	12·1
8 ,, ,, ,, ,, ...	60	15·2
7 ,, ,, ,, ,, ...	91	23·4
6 ,, ,, ,, ,, ...	58	14·7
5 ,, ,, ,, ,, ...	51	12·9
Less than 5 per cent.	27	6·8
Total	394[1]	100·0

The amount of calculated loss on a boiler plant due to excess air is shown by the curve, Fig. 8, and the average

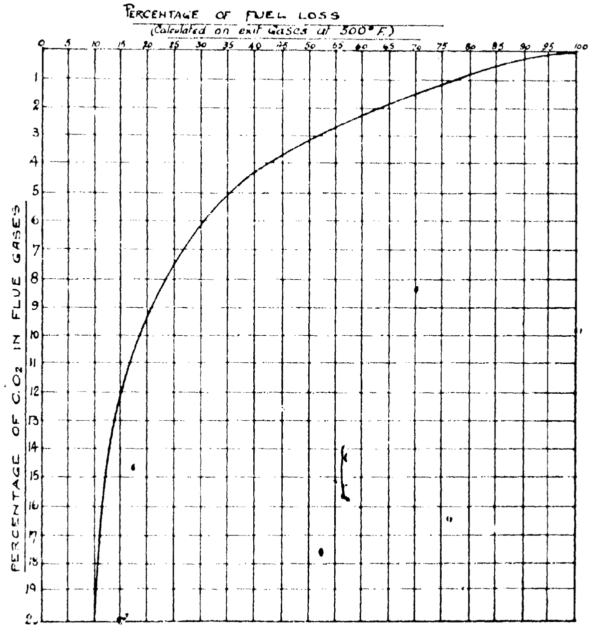

FIG. 8.—Curve showing the fuel loss for corresponding percentage of CO_2.

figure of 7·5 per cent. CO_2 corresponds to an approximate calculated loss of 11·0 per cent. in the coal bill, taking 14 per

[1] Six plants not determined.

cent. as the maximum CO_2 obtainable. That is to say, on the annual coal bill in Great Britain for steam generation of 90,000,000 tons, the loss due to low CO_2 is no less than 9,900,000 tons per annum.

With regard to the analysis for CO, there has been no option but to use hand methods, since the new "Duplex Mono," already described, is only just coming on the market.

The recommendations of the "Civils" Code with regard to the hand methods to be used for the analysis of flue gases are as follows (pp. 68-69):—

"It is essential that the temperature of the flue gases should be taken at the same point as that from which the sample for analysis is drawn. Great care must be taken to avoid their dilution by air leaking between the boiler and the surrounding brickwork, through cracks in the brickwork or through ill-fitting damper frames or other openings in the external flues.

"Since the gases cannot be assumed to be homogeneous, an attempt must be made to obtain an average sample throughout the width of the flue; it should be remembered, moreover, that (1) the gas must be drawn into the sample tube at a uniform rate per hour, (2) the gas in the dead space between the flue and the sample tube must be eliminated, (3) the gas in the sample tube must not be allowed to diffuse back again into the main tube or be drawn back into the main current by sudden changes of pressure." [1]

The note [1] is as follows, together with the illustration:—

"Condition (3) is not satisfied by any of the ordinary forms on the market. That shown in Fig. 6 (see next page) has been designed by Mr. G. Nevill Huntly to fulfil (1), (2), and (3). The gas is drawn in at A, the dead space is cleared by sucking at B; the rate at which the gas is drawn is fixed by the distance C-D, and this can be increased by joining a piece of glass tube with rubber to D. The gas in E cannot be sucked back and cannot diffuse back. The two 3-way taps greatly simplify the transference of gas for analysis."

The Code then goes on to say :—

"It is often necessary and advisable to carry out the analysis of the gases at once. One of the most convenient arrangements for this purpose is the 'Orsat' apparatus, as it requires no supply of pure water and no bottles of chemicals.

"A calibrated 'Orsat' apparatus with mercury as a confining liquid gives satisfactory results for carbon dioxide, but is not suitable for determining carbonic oxide. The commercial pattern is not recommended for the determination of oxygen. Instructions for use are issued by the makers of the different instruments.

"If the gases are analysed on the spot the determination of carbon dioxide alone is advisable; this will permit of tests every fifteen minutes. If a fuller analysis is deemed necessary a series of continuous samples should be drawn off into small tubes over mercury and analysed either during or as soon as possible after the trial."

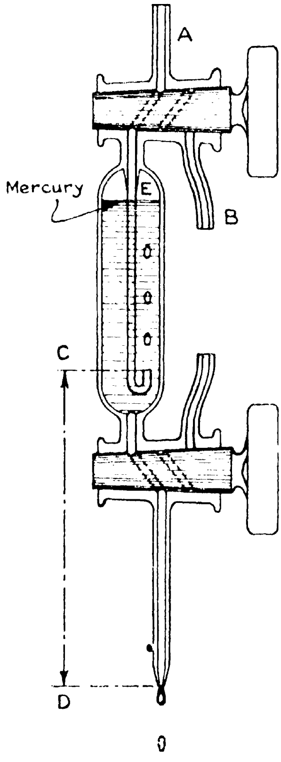

FIG. 9.
(Fig. 6 in the "Civils" Code.)

The reason of all these complications is not very clear, but seems to be due to the fallacy in the "Civils" Code of trying to calculate the efficiency of a boiler plant from the analysis of the flue gases.

It is most extraordinary that anyone should suggest that it is necessary to collect samples of flue gas over mercury. The samples taken according to the methods suggested would be so small in size that they could not possibly be an average of the vast volume of flue

gases in an ordinary boiler plant, and if we are going to use mercury to take samples even approximating to a true average, we should require hundredweights of mercury, not ounces.

All this worry about "dead space," "diffusing back," "changes of pressure," "temperature of the gas," etc., is simply a waste of time on a practical boiler test. It is quite simple to obviate it by drawing two or three samples of flue gas into an "Orsat" or other hand apparatus one after the other, and only analysing the last sample. In any case there is no need to use mercury, and a solution of glycerine and water will give results just as accurate after it has been in contact with flue gas for a short time and become saturated. The makers of the "Orsat" apparatus will be considerably astonished to learn that "the use of mercury as a confining liquid" is recommended, and also that the "commercial pattern"—whatever this may mean—is not suitable for the determination of oxygen. In any case, to carry out only four analyses per hour is nothing like sufficient to get a proper average, and, as already stated, a CO_2 Recorder will give about twenty analyses per hour. It is very little use to take "snap" tests at quarter of an hour intervals, because the composition of the flue gas varies almost continuously, as a CO_2 Recorder soon shows.

In order to collect average samples of flue gas over a period, the "Civils" Code states, on page 69:—

"For a permanent apparatus the arrangement of collecting-tubes illustrated by Mr. Breckenridge[2] is probably the best. It averages gas both for temperature measurements and gas samples. It must, however, be built into the flue, and hence is only suitable for a permanent installation. Mr. Breckenridge has shown, however, that a single steel tube closed at the inner end and perforated with a series of holes[3] throughout its length takes a good average sample; it is readily withdrawn for cleaning, and is the most practical form for temporary trials. A very much larger quantity of gas must be drawn from the flue than is taken for analysis. The sample is drawn from a small tube joined to the main aspirating

tube; the latter may be of half-inch bore, and the current may be conveniently produced by a steam- or water-ejector. A test should be made for gas-tightness before and after trial."

The notes at the bottom of page 69 are as follows:—

"[2] A study of four hundred steam tests made at the Fuel Testing Station, St. Louis, Mo., 1904-1906. 'United States Geological Survey, Bulletin 325, Washington, 1907,' page 157."

"[3] The area of these holes must be small as compared with that of the bore of the pipe, otherwise less gas will enter the tube near its closed end than elsewhere."

According therefore to the "Civils" Code we are recommended, for the collection of large samples of flue gas, to use some method devised years ago by Professor Breckenridge of U.S.A., no further information being given. Presumably when a boiler test is contemplated every one has to write out to the United States Geological Survey. Accordingly I wrote to Washington, U.S.A., and I am informed (May, 1921) very courteously that the publication in question has been out of print for a very long time and is no longer available from any official source in America. It will give some idea as to the practical value of the "Civils" Code when it recommends an American method described in some publication twenty years old, and which has apparently been out of print for years in the land of its origin.

I fail to understand what is the need of all this trouble about collecting large samples of flue gas, which is a perfectly simple operation. For a few pounds one can buy a very efficient gas collecting apparatus, which will collect say 15,000 to 20,000 c.c. of flue gas at any desired speed. For example, we have the "Hays" Gas Collector as illustrated, Figs. 10 and 11.

In this apparatus a water supply pipe is connected to the valve WV and the large tank of the collector about half filled with water, with a pint of engine oil poured on the top, so that the water in the collector does not absorb any CO_2. The inlet for the flue gas is through the valve GV on a ¼-in.

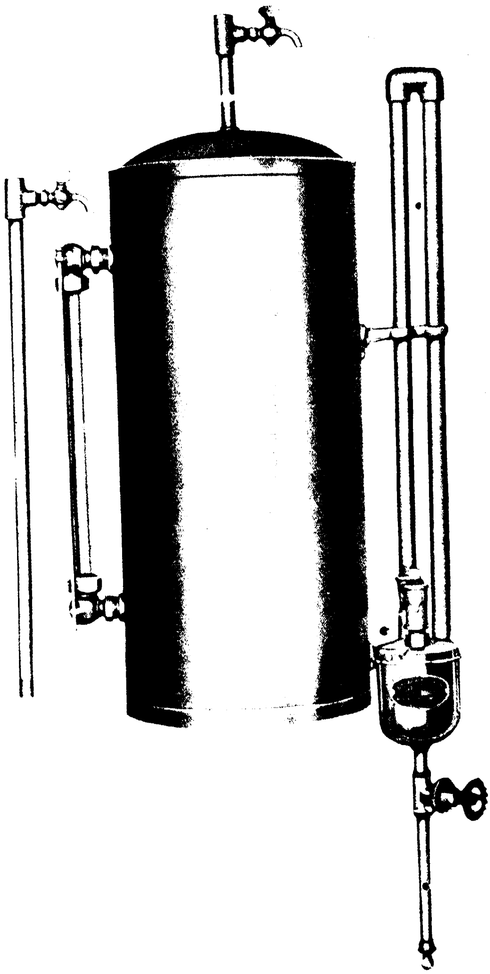

FIG. 10.—"Hays" Automatic Gas Collector.

[To face p. 77.

pipe. To work the collector the flue gas valve GV is closed, the valve GC opened and the supply of water turned on by opening the water valve WV so as to slowly fill the whole of the

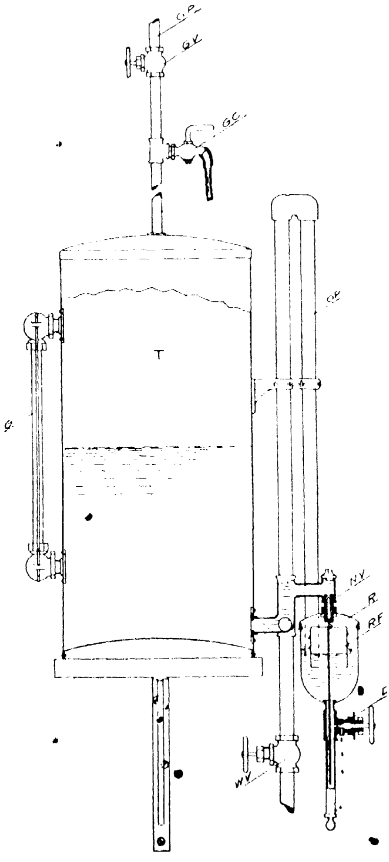

FIG. 11.—Working principle of the "Hays" Automatic Gas Collector.

collector with water until it begins to flow out of the overflow OP, when the valve WV is shut off. The valve GC is then closed and the flue gas valve GV opened.

Water will then flow from the tank T' into the flow regulator R and be discharged through the drip DC. The rate of the water, that is, of the collection of the flue gas through GV, will be absolutely steady, depending on how much DC is open and is quite regardless of the level of the water in T. If this flow regulator is not provided, a simple bottle or cylinder filled with water and allowed to empty itself will not give a true average sample over a number of hours because, as the vessel empties, the rate of flow of the water diminishes as the "head" of the water is less in the apparatus.

These gas collectors can be installed permanently at different points of the plant, and one instrument retained for carrying about for temporary installation at any other points of the plant. The sample of gas for analysis is withdrawn by the "Orsat" apparatus through the valve GC and after analysis the gas content is expelled and the apparatus is ready for use again. The content is very large, about 17,500 c.c., and the rate of collection can be fairly rapid, say, 2000 c.c. per hour.

This large sample of gas can then be analysed at leisure for CO_2, CO and oxygen, and the figure for CO_2 will be a useful check on the CO_2 Recorder.

I would suggest, therefore, that the International Code insists upon a large sample of gas being taken continuously, say 2000 c.c. per hour, and this large sample be then analysed for CO_2, CO and oxygen.

The next question is the points at which to draw the samples of flue gas, and this concerns also the methods of calculation. In the "Civils" Code flue gas analysis is intended primarily, as already stated, as a basis for the "heat balance" of the plant and therefore it is necessary to draw samples of gas from the chimney base, that is the final exit of the plant, so as to calculate—from the analysis of the gas—the amount of heat lost by the plant. I propose to discuss in detail the method of calculation in later pages, but will say here that in my opinion this method of calculation is not so accurate, and

is infinitely more complicated and troublesome, than the simple method based on the actual heat in the coal.

The difficulties of the "Civils" Code method are shown by the following paragraph from the code (p. 70):—

"Since the amount of heat carried away by the flue gases is proportional to their volume, and this volume is at any instant inversely proportional to the amount of carbon dioxide by volume, the mean percentage found from a recording instrument or from the analysis of an average gas sample is not exactly that required. The error from this cause, with a boiler fired from a mechanical stoker, will probably be under 0·1 per cent. of CO_2; with a hand-fired boiler it may be as high as 0·5 per cent.; with, say, 10 per cent. of carbon dioxide in the flue gas this would mean errors of 1 per cent. and 5 per cent. respectively in the heat balance, and renders unnecessary a higher accuracy than 0·1 per cent. on the carbon dioxide; for this accuracy to be reached the gas sample must be collected over mercury. Considerable errors may occur if water is used, and the next best fluid to mercury is a mixture of equal volumes of glycerol and water, when the error would probably not exceed 0·4 per cent.

"The apparatus used for gas analysis, therefore, must be correct to 0·1 per cent. for carbon dioxide and oxygen, 0·05 per cent. for carbon monoxide, and 0·02 for methane. These correspond roughly on an average heat balance with about 0·25 per cent. of the total heat available.

"When boilers are fired by mechanical stokers, the gas samples may be drawn directly into an analysing apparatus, but when the firing is by hand continuous collection is necessary to ensure correct results.

"When all the gas aspirated passes into the collecting-vessel the volume of the aspirating-tube must be very small compared with the volume of the vessel into which the gas is drawn, otherwise the sample collected will contain little besides the gas lying in the tube when the collection was begun."

I suggest in the International Code to abandon entirely this "heat balance sheet" method of calculation, and to take the samples of flue gas as near the furnace as possible, so as to get proper information as to the state of the firing. That

is to say, the sample pipes, say $\frac{1}{2}$-inch W.I., should be placed in the downtake or side flues of "Lancashire" or "Cornish" boilers, in the furnace exit of water-tube boilers, the front uptake on marine boilers and so on. Samples can of course be taken at various other points as already described, to detect air leakages, and an efficient permanent installation for a CO_2 Recorder, with connection to take samples for hand analyses, has pipes with valves connected to all the points, so that any point on the plant can be switched on to the CO_2 Recorder at will, whilst at the same time the gas is filtered from dust and dirt through a filter, and a continuous current of gas maintained through the circuit to do away with "lag" errors.

6. **The Method of Measuring the Boiler Feed-Water.**—In order to measure the amount of water evaporated there are two general methods that can be adopted, namely, (1) weighing the water or measuring its volume in tanks, and (2) using a water meter. A third possibility, that of measuring the output of the plant as actual steam by means of steam meters, will be discussed later (p. 131).

The "Civils" Code gives a most elaborate account, occupying no less than eleven pages (pp. 38-49), of the methods to be used, insisting on the tank method only, even at sea. The reference to water meters is as follows (p. 46, No. 6, "Feed Meters"):—

"Feed meters are not recommended for scientific trials, but as some makes appear to be capable of giving results within 1 per cent. of accuracy, they may be usefully employed in many cases when it is desired to obtain an approximate idea of the normal performance of the boilers; they should, however, be calibrated before and after the trial with water at the temperature of the feed. A "Venturi" meter, for instance, or a notch gauge, may be used for the continuous measurement of water when the quantity is large, and the flow is fairly steady, as giving fairly accurate results."

This is altogether a most remarkable paragraph. It is stated that some meters "appear to be capable" of giving

results accurate to 1 per cent., in which case they can be used when "approximate" results are obtained. If any water meter is accurate to 1 per cent., then in my opinion it is probably more accurate than the "Civils" method of weighed tanks, and much more suitable for all boiler trials, no matter how "scientific". I have had a fairly long experience of boiler trials carried out by means of tanks, and even when the greatest care is taken, very few trials are accurate to 1 per cent. by this method. The operation is in practice extremely clumsy and tedious, and the observers quickly get tired of the monotonous operations, so that errors soon tend to creep in every time a tank is filled and emptied. Further, whilst a meter can be calibrated "before and after the trial" and any errors detected, it is impossible to do this with the tank method, although the error is likely to be as much, if not more, than a water meter.

As with CO_2 Recorders, the above paragraph may have applied to 1897-1901, when the "Civils" Code originated, but to say that it applies at the present time, or even in 1913 when the Code was revised, is quite wrong. There are at the present time nearly twenty different makes of boiler feed meter, British and American, on sale in this country; apart from many continental meters, and for the "Civils" Code to maintain that *all* these meters are not accurate enough for the very purpose for which they are specifically designed, namely, boiler testing, is a very strong statement, to say the least of it, and one which is made without any apparent justification.

The American "Mechanicals" Code is, as usual, much more up-to-date and states the following (p. 12):—

"9*b*. *Water Weighing and Measuring Apparatus*.—(1) *Feed-water*.—Wherever practicable the feed-water should be weighed, especially for guarantee tests. The most satisfactory and reliable apparatus for this purpose consists of one or more tanks each placed on platform scales, these being elevated a sufficient distance above the floor to empty into a receiving tank placed below, the latter being

connected to the feed pump. Where only one weighing tank is used the receiving tank should be of larger size than the weighing tank, to afford sufficient reserve supply to the pump while the upper tank is filling. If a single weighing tank is used it should preferably be of such capacity as to require emptying not oftener than every five minutes. If two or more tanks are used, the intervals between successive emptyings should not be less than three minutes. Measuring tanks calibrated by weighing may also be used.

"In tests of complete steam power plants, where it is required to measure the feed-water without unnecessary change in the working conditions, a water meter may be employed. Meter measurement may also be required in many other cases, such as locomotive and marine service. The accuracy of meters should be determined by calibration in place under the conditions of use.

"If a large quantity of water is to be measured, an automatic water-weigher, a rotary, disk, or Venturi meter, a weir, or some form of orifice measurement may be employed. In any case the measuring apparatus should be calibrated under the conditions of use, unless its design is such that standard formulæ and constants may be applied for determining the discharge. If recording mechanism is employed in connection with orifice or weir measuring apparatus, make sure that its record is reliable."

This statement is, however, not quite fair to water meters in general, and most meters can be used quite well for the smallest boiler plants.

It will be noted that the wording as regards "Venturi" and "Notch" meters is very much the same in the two Codes, and it is very curious that the "Civils" Code has quite a number of references to specific American conditions, such as the "Barrus" calorimeter (p. 57), the "Breckenridge" method of gas collection (p. 75), and the question of three hours' duration of the test (p. 53).

It is interesting to give the names and types of the various boiler feed meters on the British market. Such meters are divided into two general classes: (*a*) open, non-pressure types, and (*b*) closed, pressure types.

The first class consist of (1) *Automatic Water Weighing Machines* in which a small tank is continually filled with water to a certain weight, when it is released, and the water falls into the boiler feed tank, the number of such small weighed tanks being recorded on a train of wheels mechanism. Of this type there is the "Avery Automatic Water Weigher," the "Leinert Meter" and the "Sarco Tippling Meter". (2) "*V Notch Meters*," in which the water flows through a "V" notch of given dimensions, and, by means of a float mechanism, a continuous record is kept of the height of the water in the notch, the amount of water passing being proportional to the height in the notch. Of meters on this principle there is the "Bailey Meter," the "Kent V Notch Recorder," the "Lea V Notch Recorder," the "Paterson Fluxograph" and the "Rheograph Water Flow Recorder". (3) "*Weir Meters*," on the same principle as the last, but using a "weir" instead of a "V" notch, represented by the "Simmance-Abady Precision Meter".

In the second class, the meter is placed between the boiler feed pump and the economiser, or, in fact, at any point of the circuit between the feed pump discharge and the boiler feed valve. In the case of an injector the meter must be on the suction side, and can also, if necessary, be on the pump suction. Pressure meters are divided into the following classes :—

(1) *Piston Meters* in which the pressure of the water actuates in its travel a double acting piston, so that each stroke of this piston represents a definite amount of water, the number of strokes being recorded by a train of wheels mechanism. Meters of this type are the "Kennedy," "Sarco" and "Worthington Duplex".

(2) *Rotary Meters*, in which the pressure of the water actuates a rotary displacer, wheel, disc, or other appliance, one revolution corresponding to a definite amount of water, and the number of revolutions being recorded by means of the usual train of wheels mechanism. This type is represented

by the "Kent Uniform" Meter, the "Leeds" Meter, the "Sarco Disc" Meter, the "Siemans Disc" Meter, the "Siemans' and Adamson" Meter, and the "Worthington Turbine" Meter.

(3) "*Venturi Meters*" on the principal of the "Venturi" tube, such as the "Bailey Fluid Meter C4," and the "British Thomson-Houston" Meter.

A water meter has two very great advantages over any tank method. In the first place, it is much more convenient and reduces the trouble and worry of boiler testing to an astonishing degree. Secondly, it has the very great advantage that it enables a boiler plant to be run on the only possible lines for the highest of efficiency, namely, that of continuous testing all the year round. It is absolutely essential that a weekly record be kept of the water evaporated on a boiler plant, together with the amount and analysis of coal burnt, and other vital figures, and the water meter is practically the only possible method of doing this. The "Civils" Code in this respect is not devised on practical lines, and is obviously only intended for an occasional test, as it would be almost impossible to carry out even a week's trial on the methods recommended. For trials at sea, and for locomotives, the advantages of the closed type of meter will be obvious.

The trouble is, of course, that all water meters are not equally accurate, and it would be rather a delicate matter for me to attempt to give an opinion as to the accuracy or otherwise of any individual meter. I would suggest that this be one of the investigations to be carried out by the Committees engaged in devising the International Code, and that a list of "approved" meters be issued after such investigations are complete; any one of these approved meters, under suitable conditions, to be allowed for use on an official test, in addition, of course, to the tank method if desired.

Whatever meter is used, it must be installed with a byepass arrangement, and a testing tank. The method of installation I recommend, from long practical experience, for per-

manent installation for a pressure type of meter is illustrated in Fig. 12.

A is the water meter and F a small calibrated test tank, (say 6000 lbs. capacity). Normally, the feed-water flows

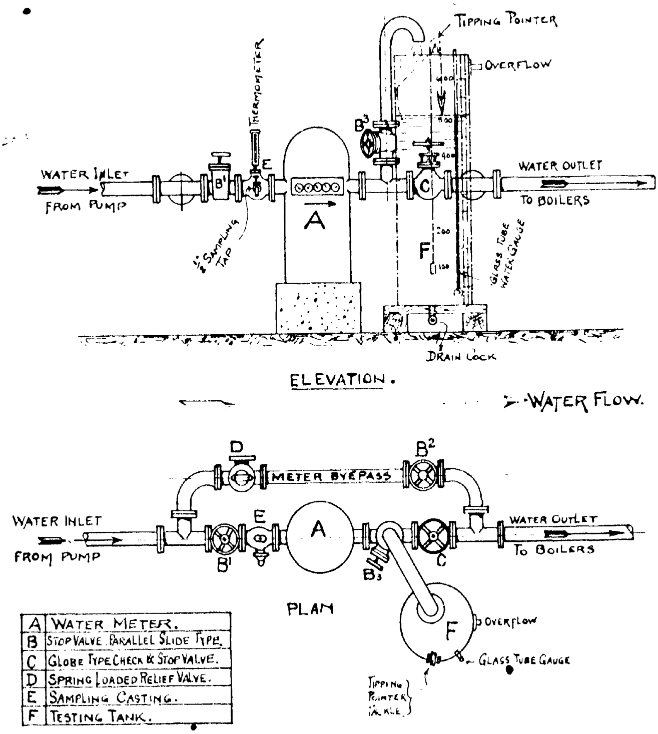

FIG. 12. Typical installation recommended for a boiler feed meter (pressure type).

through the stop valve B_1, the sampling casting E, the meter A, the combined stop and check valve C and on to the boiler plant. B_1 is an ordinary parallel slide stop valve, E is a simple "sampling casting" of my own design, containing a thermometer socket to read the temperature of the feed-water actually passing through the meter, whilst at the

same time a tap is provided to take a sample of the water. The valve C is an ordinary stop valve, but loose on the spindle so that it acts also as a non-return (check) valve. The object of this is to obviate any back pressure action on the meter and make the travel in the meter absolutely "forward" only. On the bye-pass is a safety valve D as a safeguard to the meter, and in this position it acts for both bye-pass and normal feeding. In case of necessity the meter can be shut out of the circuit by closing valves B_1 and C and opening valve B_2. In order to test the meter when running normally, all that is necessary is to shut valve C and open valve B_3 to the test tank.

I devised and used the above method long before I ever read the American "Mechanicals" Code, but in this Code the following almost identical method is recommended (p. 155) :—

"*Calibrating Water Meters.*—227. Referring to Fig. 2, two tees A and B are placed in the feed pipe and between them two valves C and D. The meter is connected between the outlets of the tees A and B, and the valves E and F are placed one on each side of the meter. When the meter is running, the valves E and F are opened, and the valves C and D closed. A small bleeder G is kept open to make sure that there is no leakage. A gage is attached at H. When the meter is tested, the valves C, D and F are closed, and the valves E and I are opened. The water flows from the valve I to a tank on platform scales. In testing the meter, the water is throttled at the valve I to obtain the desired rate of discharge, the gauge meanwhile showing the working pressure. The piping leading from the valve I to the tank is arranged with a swinging joint, consisting merely of a loosely fitting elbow, so that it can be readily turned into the tank or away from it. When the desired speed has been secured, the end of the pipe is swung into the tank at the instant the pointer of the meter is opposite some graduation mark on the dial. When the required number of cubic feet are discharged, the pipe is swung away. The tests should start and stop at the same graduation mark on the first dial, and continued until at least, 10 or 20 cub. ft. are discharged for one test. The tank is weighed before and after filling.

"228. The water passing the meter should always be under pressure so that any air in the meter may be discharged through the vents provided for this purpose. Care should be taken that there is no unnecessary air drawn into the feed-water. The meter should be tested before and after the trial, and repeated calibrations should be made to obtain confirmative results.

"229. Fig. 2[1] and the description apply to a piston meter, but any other type of meter carrying water under pressure may be calibrated in the same manner."

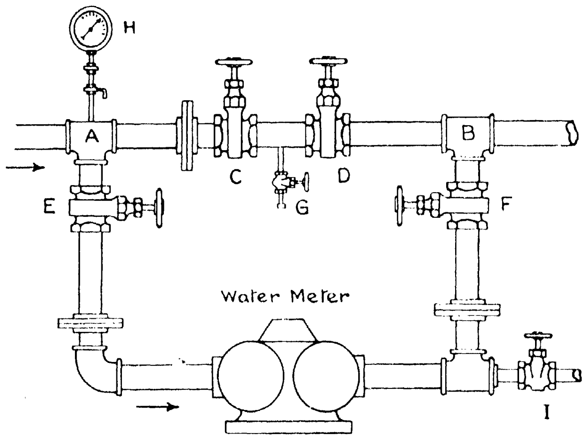

FIG. 13.—Meter calibration. (American Mechanical Engineer's Code, Fig. 2.)

The note[1] says :—

"[1] Reproduced from 'Trans. Am. Soc. M. E.,' vol. 24, p. 724, fig. 118."

By such methods the accuracy of the meter can be checked at any time in less than half an hour. The "Civils" Code might very well have stated that one of the advantages of the tank method is that it is always certain in the sense that any error is small, whereas if a meter does go wrong, the error may be very great and uncertain, as it may be high or low, or commence suddenly. By using a testing tank, therefore, as

described, in conjunction with a water meter, the possibilities of error are reduced to a minimum, and comparable, for example, only to the possibility of making a mistake in the actual number of tanks used on a test according to the "Civils" Code. For a very large boiler plant and a permanent installation, I recommend, as an absolute certainty, two different makes of meter in series with testing tank, as the expense of an extra meter is trifling in comparison with the advantages obtained.

7. **Moisture in the Steam**.—Another of the great practical difficulties in the way of a scientifically accurate boiler plant test is that steam, unless superheated, always contains some water. The amount is generally 1 to 2 per cent., but may be anything from zero to even 5 per cent. Theoretically, of course, such water must be deducted, as it is included as steam (with the full absorption of latent heat) in the amount of water evaporated, and if not deducted, makes the efficiency of the boiler plant too high.

Both the "Civils" and the American "Mechanicals" Codes state that this moisture in the steam must be determined, and deducted in calculating the efficiency. The "Civils" Code, however, goes on to point out the difficulties as follows (p. 52):—

"No. 15. *Measuring the Moisture in Steam.*—Up to a certain limit, depending on the steam velocity, the moisture can be measured by one of the forms of calorimeter in the market; these instruments are not generally reliable when the moisture exceeds about 2 per cent., as it then appears to creep along the walls of the pipes and does not all enter the calorimeter. It is therefore desirable to provide the steam-pipe with a steam-drier, and to measure the quantity of water which is discharged by an automatic trap; and also to measure the moisture of the steam after it has passed the steam-drier. Opinions differ as to whether it is best to collect the steam by a perforated tube fixed across the diameter of the steam-pipe or by a tube arranged to collect from the centre only of the steam-pipe, but the former method is in more general favour."

Further references to the question of moisture in steam are (p. 78):—

"Full information should be given as to the method of determining the weight of the moisture present in the steam, and how it was trapped, or collected, and weighed."[1]

The note[1] says:—

"See paper by Dr. W. C. Unwin, 'Proc. Inst. Mech. E.,' 1895, p. 31."

The chief difficulties are that the ordinary steam calorimeters, whether of the throttling or separating type, are not very accurate at the best of times, and particularly, as stated, when the moisture is over 2 per cent.; there is no known satisfactory method of obtaining a true average sample of steam; and further, the steam also has generally a violent swirling motion as it passes along the pipes, especially in the neighbourhood of bends, valves, etc., which does not make the sampling any easier.

The "Civils" Code is compelled, therefore, to recommend the laborious proceeding of inserting a special steam drier in the steam pipe, measuring the amount of water discharged from the drier by means of an automatic trap, and then determining the moisture left in the steam, by means of a steam calorimeter, after it has passed the steam drier. In this connection it may be pointed out that the modern type of steam-drier such as the "Stefco" and the "Tracy" are not placed in the steam pipe circuits, but in the boiler itself. There is, consequently, no trouble in fitting them, and they will separate the moisture so that the steam contains certainly less than 1 per cent., and may be absolutely dry.

It is also very difficult to know where to take a sample of steam issuing from a boiler. If it is drawn from the vertical branch pipe a few inches above the boiler shell there is trouble due to "showers" of condensed steam, and the percentage of moisture shown is apt to be too high. On the other hand,

the sample must be taken close to the boiler to avoid inaccuracies due to cooling and condensation.

The American "Mechanicals" Code states (p. 18):—

"9m. *Steam Calorimeters.*—The most satisfactory instruments for determining the amount of moisture in steam are calorimeters that operate upon the throttling principle, or that combine the throttling and separating principles; the orifice used being of such size as to throttle to atmospheric pressure, and the instrument being provided with two thermometers, one showing the temperature above the orifice and the other that below it. If no commercial make of calorimeter is available on a test, an instrument of the throttling type can be made of pipe fittings as shown in Appendix No. 11. Instruments working on the separating principle alone may also be employed; also certain forms of electric calorimeters. See 'Trans. Am. Soc. M. E.,' vol. 28, p. 616."

The Appendix 2 is a detailed description of a throttling calorimeter. As regards the method of sampling the steam the American "Mechanicals" Code has the following (p. 35):—

"*C. Sampling Steam.*—28. Construct a sampling pipe or nozzle made of ½-in. iron pipe and insert it in the steam main at a point where the entrained moisture is likely to be most thoroughly mixed. The inner end of the pipe, which should extend nearly across to the opposite side of the main, should be closed and the interior portion perforated with not less than twenty ⅛-in. holes equally distributed from end to end and preferably drilled in irregular or spiral rows, with the first hole not less than half an inch from the wall of the pipe.

"The sampling pipe should not be placed near a point where water may pocket or where such water may affect the amount of moisture contained in the sample. Where non-return valves are used, or where there are horizontal connections leading from the boiler to a vertical outlet, water may collect at the lower end of the uptake pipe and be blown upward in a spray which will not be carried away by the steam owing to a lack of velocity. A sample taken from the lower part of this pipe will show a greater amount of moisture than a true sample. With goose-neck connections a small amount

of water may collect on the bottom of the pipe near the upper end where the inclination is such that the tendency to flow backward is ordinarily counterbalanced by the flow of steam forward over its surface; but when the velocity momentarily decreases the water flows back to the lower end of the gooseneck and increases the moisture at that point, making it an undesirable location for sampling. In any case it should be borne in mind that with low velocities the tendency is for drops of entrained water to settle to the bottom of the pipe, and to be temporarily broken up into spray whenever an abrupt bend or other disturbance is met.

"29. If it is necessary to attach the sampling nozzle at a point near the end of a long horizontal run, a drip pipe should be provided a short distance in front of the nozzle, preferably at a pocket formed by some fitting, and the water running along the bottom of the main drawn off, weighed, and added to the moisture shown by the calorimeter; or better, a steam separator should be installed at the point noted.

"30. In testing a stationary boiler the sampling pipe should be located as near as practicable to the boiler, and the same is true as regards the thermometer-well when the steam is superheated."

The use of a steam calorimeter at all is a laborious, hot and generally most unpleasant job, and I am afraid that if the "Civils" Code is to be following in this respect, there will be in practice more trouble in determining the moisture in the steam than in testing all the rest of the plant put together. As a consequence, in very few boiler trials is the moisture in the steam determined, and practically all the 400 boiler tests we have carried out have been average in this respect.

I would suggest that in the International Code, the determination of the moisture in the steam be abandoned entirely, as the results are dubious and not worth the trouble, and that this question be investigated by a future Committee with a view to settling the point definitely. It certainly seems a feasible proposition to insert steam driers in the boilers themselves, as already mentioned, since these modern driers increase the economy of the boiler plant, and the steam could then be taken as free from moisture.

In plants fitted with superheaters there will of course be no inaccuracy, but, unfortunately, superheaters are comparatively little used in this country. Thus out of the 400 plants only 114 (28·5 per cent.) were fitted with superheaters, and most of these only partially equipped. For plants without superheaters the efficiency results would therefore be a little too high.

In practice, however, by a little care this error can be reduced to a minimum by keeping the water at a reasonable height in the gauge glasses. Most boilers in Great Britain are working much below their proper rated output, so that moisture in the steam is not excessive, and for testing any plant for guarantee the amount of evaporation can be specified so that the conditions with and without the appliance will be the same in this respect. As usual, of course, the moisture determinations, by means of a steam calorimeter, can always be added to the International Code by arrangement for any particular test.

8. **Specific Heat of Superheated Steam.**—With regard to this point, the "Civils" Code gives the following (p. 50):—

> "No. 13. *Specific Heat of Superheated Steam.*—Experiments have for some years past been carried out with the object of ascertaining the amount of heat that is represented by various degrees of superheat, but definite results have not yet been obtained.
>
> "As far as our present knowledge extends the value 0·48 may be adopted for the purposes of this report. Every 100° F. superheat then represents about 4 per cent. of the total heat of the steam, and an error of 0·01 in the value of this specific heat would not affect the results of the calculations by more than 0·1 per cent.[1]"

The note [1], at the bottom of the page, is as follows:—

> "[1] The values given in Marks and Davis's Tables are generally accepted. A chart giving 'mean specific heat' of superheated steam over a wide range of temperatures and pressures will be found in 'Principles of Thermodynamics,' by G. A. Goodenough. 2nd ed. London, 1912."

This hardly seems to be the right point of view in 1922. ·48 is the specific heat figure as originally determined by Regnault and Hirn. Hirn's formulæ was :—

Specific heat at constant pressure is $= 0{\cdot}4304 + 0{\cdot}0003779\,T$

$$(T = \text{temp. } ^\circ F.)$$

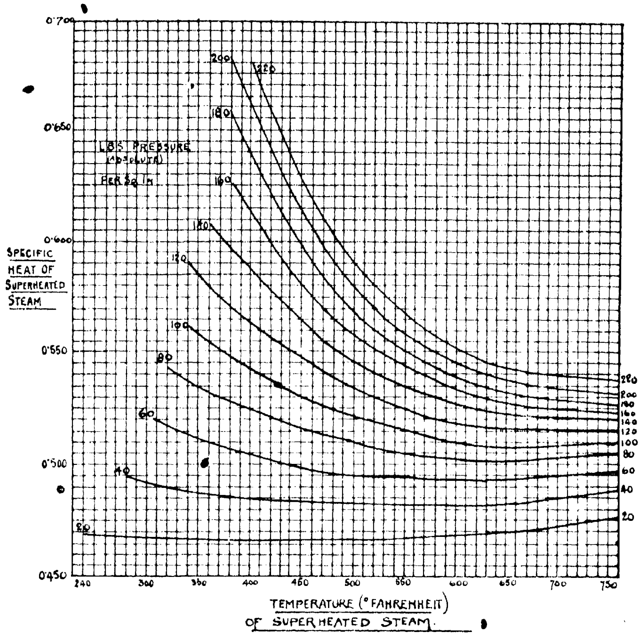

FIG. 14.—Curve showing the specific heat of superheated steam (Knoblauch and Jakob's figures).

This, however, is only correct for atmospheric pressure. The figures for the specific heat of superheated steam at different pressures have been determined with great accuracy by Knoblauch and Jakob, of the Royal Technical University, Munich, and are given in any book on steam tables, in the form of the curve Fig. 14, and I would suggest, therefore, that in the International Code these figures be taken as official for

the calculations. The figures vary from about 0·45 to 0·685 ; thus, in the examples I have given in the specimen Complete Report according to the suggested International Code (p. 149), the temperature of the superheated steam is 559° F. and the boiler pressure 162 lbs. absolute, with a corresponding saturation temperature of 364·2° F. From Knoblauch and Jakob's table, the specific heat of superheated steam for these conditions is 0·54, whereas of course the "Civils" Code would take it as 0·48. The difference may not be great, but we might as well use the accurate figures, especially when it is no more trouble.

9. **Steam or Power Used Auxiliary to the Production of Steam.**—One of the most serious defects in both the American "Mechanicals" and the "Civils" Codes is the scanty attention given to the question of steam or power used auxiliary to the production of steam, and this fact alone largely destroys the real value of any boiler plant test carried out according to either of the codes. To illustrate this point, it is best to start with the simplest possible boiler plant, namely, one boiler, hand-fired, with injector feed and natural chimney draught. Apart from the infinitesimal amount of heat taken as energy in working the injector (the latent heat of the steam used being returned to the boiler) all the steam produced from this boiler is useful steam ready for the factory. That is, if 5000 lbs. of water is evaporated per hour, 5000 lbs. of steam is ready at the boiler stop valve for useful work, and the real net working efficiency of the plant is calculated on this 5000 lbs. evaporation.

But if we now add to this simple boiler plant any appliance to help in generating the steam, and this appliance takes some steam directly or indirectly to work it, then this latter steam must be deducted from the evaporation in calculating the real net working efficiency of the plant.

For example, if a steam jet furnace, hand or mechanically fired is added to the plant, and the amount of steam taken by the steam nozzles is 10 per cent. of the production of the

boiler, that is, 500 lbs. per hour, then the real net *production* of the boiler plant is only 4500 lbs. useful steam per hour (5000 – 500) in spite of the fact that the boiler is still evaporating 5000 lbs. The net working efficiency must be calculated on the 4500 lbs., that is, the real amount of steam available for useful work. This may sound elementary and obvious, but it is at any rate not clear to the Committees who devised the two Codes, and it is conveniently ignored in practically every boiler plant test that has ever been published. Thus at the present time we have firms making appliances for steam generation, advertising broadcast figures of tests carried out with their particular appliances, in which results of 75 to 80 per cent. boiler plant efficiency are shown, and the fact that the appliance itself may be wasting say 2½ to 20 per cent. of the steam production of the whole plant is coolly ignored.

It surely must be obvious that all steam used in connection with the production of the steam must be deducted, and from the point of view of real net working efficiency the boiler plant must be regarded as being in a closed box, into which a certain amount of heat as coal or other fuel is thrown at one end, and a certain lesser amount of heat as useful steam comes out at the other end, as shown in Figs. 15 and 16.

The references given to this vital point in the "Civils" Code are so confusing that one can only say that no definite instructions are given at all. These references dissected from the Code are as follows (p. 7):—

"It is particularly desirable that arrangements should be made for supplying the steam used by auxiliary apparatus, such as steam blast, fans, pumps, etc., from a separate boiler entirely disconnected from that under trial,[1] separate feed-measuring apparatus being provided if it is desired to ascertain the quantity of steam thus used. If such auxiliary boiler cannot be blanked off during the trial, the pressure in it should, if possible, be maintained the same as that in the boilers under trial, in order to minimise leakage through the stop-valve".

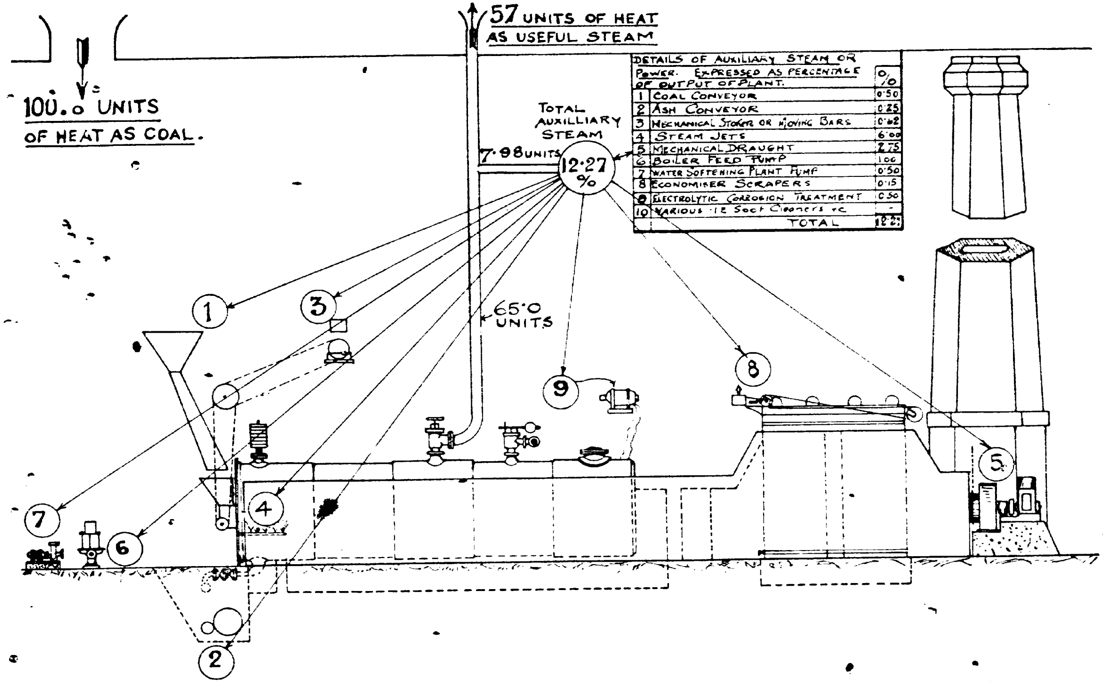

FIG. 15.—Illustration of a typical cylindrical boiler plant showing in detail the steam or power that may be used auxiliary to the production of steam.

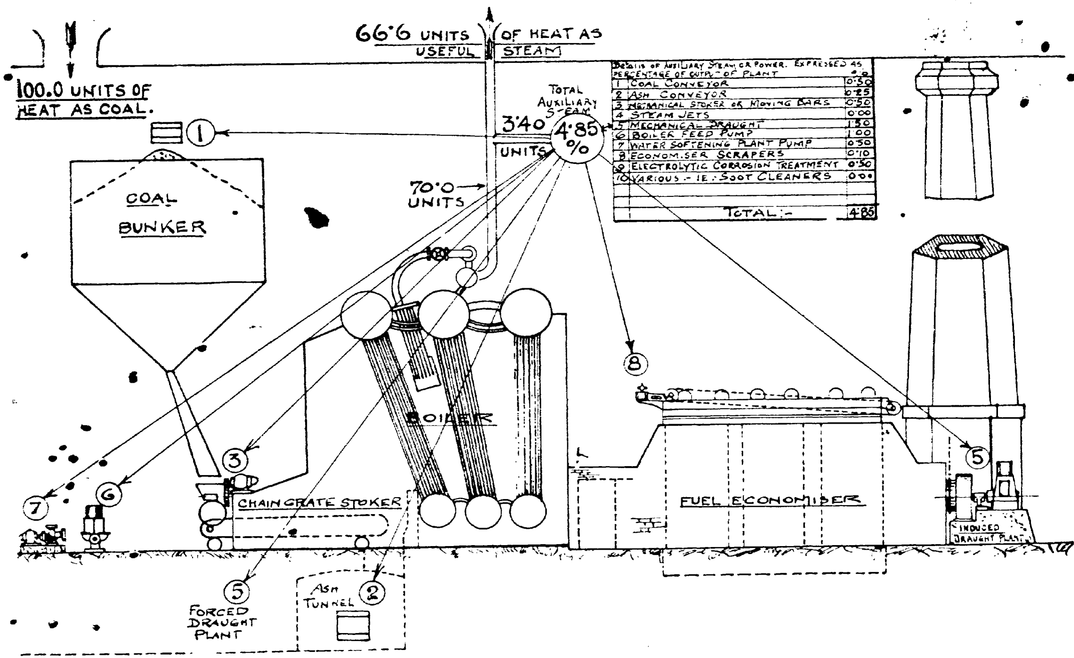

FIG. 16.—Illustration of a typical water tube boiler plant showing in detail the steam or power that may be used auxiliary to the production of steam.

The above note[1] refers to page 70, and is as follows:—

"No. 30. *Steam Used by Steam Jets and Fans.*—Many mechanical stokers are provided with steam jets under the bars, others require steam for actuating the mechanism of the fans. The necessary steam may, under special conditions, exceed 10 per cent. of the quantity produced, and should be subtracted from the weight of feed-water (unless the efficiency of the heating surface is in question) because it is not available for useful work".

There is also the following:—

Page 74, paragraph "Line 3". "If mechanical stokers are used, the name of the stoker should be stated, and also whether it was of the sprinkling or coking type, unless the information has already been given in Line 1. It is desired, if possible, to give particulars of the power needed to work the stoker and how supplied."

Page 74, paragraph "Line 4". "If any system of forced or induced draught is used it should be carefully explained, and the positions and any peculiarities of the draught gauges be described: data as to the power needed or steam used should be supplied, if possible."

Page 78 "Line 30". "Wherever possible the amount of steam employed in producing the draught (whether an actual steam jet is used or whether the steam is used in working an engine for driving fans) should be given, and it should be determined by an independent test. The steam which is blown through nozzles, can, however, with a reasonable degree of accuracy, be calculated by the formula on page 71 (Sect. 30)."

It is obvious, therefore, that the "Civils" Code in general regards the determination of the steam or power used as of little or no value, although "it is desirable if possible" to undertake it. In fact, so little importance do they attach to this question that they do not even trouble in the calculations to give an example, although a number of pages are devoted to explaining how to calculate a "heat balance sheet" from the flue gas analysis, a matter of relatively little moment. Thus also on page 5 it is stated that:—

"The principal measurements are those pertaining to the weighing of the fuel and the determination of its quality; to the weighing of the water evaporated, and to the measurement of the power produced. The data thus obtained suffice to determine the thermal efficiency of a boiler."

In the American "Mechanicals" Code the following appears (p. 47, §58*b*):—

"*Correction for Steam or Power Used for Aiding Combustion.*—The quantity of steam or power, if any used for producing draught, injecting fuel, or aiding combustion, should be determined and recorded in the Table of Data and Results. This should also be recorded by foot-note below the table, a statement showing whether or not a deduction has been made from the total evaporation for steam or power so used, and if such deduction has been made, the method of computing it."

The American Code, therefore, only considers auxiliary steam or power as a matter for a foot-note, and leaves it apparently to the fancy of the engineers in charge as to whether they bother to deduct it or not.

The various points of the plant, where such auxiliary steam or power is used (already given in Figs. 15-16), considered in detail, are as follows:—

(1) *Mechanical Coal and Ash Handling.*—The amount of steam or power taken here is not excessive. An average sized plant of three "Lancashire" boilers handling, say, 90·0 tons of coal per week will take approximately, say, 3 h.p. reckoned as continuous working. The determination of the h.p. and its equivalent in steam production on the plant, can be determined without trouble. Thus, if a small non-condensing steam engine is used, the figure of 30 lbs. of steam per i.h.p. can be taken, and the h.p. of the engine calculated in the ordinary way. Such a result will be accurate to 10 per cent., which is near enough as this particular item is only a small one.

(2) *Mechanical Stoker or Moving Hand-fired Bar Drive.*—Here again, the power is not particularly excessive, averaging

1 to 2 h.p. per boiler in most cases, say 30 to 60 lbs. of steam per boiler per hour, or 0·4 to 0·8 per cent. of the production, and can be calculated as in item (1).

(3) *Steam Jets.*—The question of steam jets is undoubtedly the worst feature of this question of auxiliary steam, and the "Civils" Code does not realise the importance of it. It admits in one paragraph that the amount may be 10 per cent. of the production, and then in another, contents itself with a pious expression that the amount should be determined if possible. There is not the slightest indication given that it is just as essential to determine this figure as it is that of the amount of water evaporated and the coal burnt, and that without the figure any boiler test is practically useless.

As further showing the minor importance attached to this point by the "Civils" Code we have the following (p. 71):—

"The steam which is blown through nozzles can, with a reasonable amount of accuracy, be calculated with the help of the formula :—

Q – lbs. of steam per minute $= P \times a$
where P = the steam pressure above that of the atmosphere (i.e. it is the gauge pressure) plus 7·5 lbs.

and a is the sectional area in square inches of all the nozzles. This formula gives too high results for pressure below 50 lbs. per square inch. P should be measured near the nozzles. If the steam is superheated, the weight of steam, as found above, must be multiplied by the square root of the ratio of the absolute temperatures (t + 459) of the saturated and superheated steam."

I maintain that such an empirical formula is absolutely worthless for determining the real amount of steam used by nozzles.

In the first place, it is impossible to determine with any reasonable amount of accuracy the area of a number of nozzles. For example, a given steam jet furnace may have anything from 6 to 64 nozzles per boiler, and these nozzles soon wear larger by the friction of the steam, the holes being then, as a

rule, irregular in shape. It is a hopeless job, under these conditions, on an average sized boiler plant of, say, four boilers, with anything from 100 to 200 nozzles, to get the real area of all these nozzles.

I once tested a boiler plant of thirty-two "Lancashire" boilers with 14 nozzles per boiler, that is, a total of 448 nozzles on the plant, and the "Civils" Code seriously suggests that the only way in testing this plant would be to try and measure the irregular area of 448 different nozzles worn by the steam, each nozzle having to be taken off by means of pliers, and then replaced. Also, such nozzles are supplied as a rule from each boiler independently by a small steam pipe, which may be ½ to 1 in. in diameter, and this pipe is provided with a stop-valve which is often worked partially open, so that the actual area of the nozzles is in any case not a criterion of the amount of steam passing.

The American "Mechanicals" Code recommends the use of steam meters, but allows also various empirical methods, as given below (p. 13):—

9c. *Steam Measuring Apparatus.*—Various forms of steam meters may be employed for measuring steam, provided such meters are properly calibrated under conditions of use, and the pulsations of pressure, if any, are not serious. For measuring the steam used by the auxiliaries of a steam plant, either individually or collectively, the orifice form of steam meter may be used, consisting of an orifice in a plate inserted between the two halves of a pair of flanges in the pipe through which the steam passes, or placed in a bye-pass through which the steam is diverted, with gage pipe on either side for determining the fall of pressure. The quantity of steam represented by the various differences of pressure which occur, may be found by arranging the apparatus so as to draw steam through the orifice, and discharge it into a tank of water resting on platform scales, by which its actual weight in a given time is determined.

"A plate ⅛ in. thick containing an orifice 1 in. diameter, with square edges, will discharge the approximate quantities of dry steam per hour given in Table I., with various pressure drops, the pressure below the orifice being 100 lbs. by gage.

TABLE I.—DISCHARGE THROUGH ORIFICE 1 IN. DIA. AT 100 LBS. PRESSURE.

Pressure Drop, Lbs. Per Sq. In.	Lbs. of Dry Steam Per Hour.
½	430
1	615
2	930
3	1200
4	1400
5	1560
10	2180
15	2640
20	3050

"The water-glass method affords an approximate means for determining the steam consumption of auxiliaries, and for measuring the leakages of steam and water from the boiler and its connections. (See Appendix No. 3 for description of water-glass method.)"

The empirical "water-glass" (*i.e.*, gauge glass) method is described as follows (p. 154):—

"(*b*) *Water-Glass Tests of Leakage.*—224. To determine the leakage of steam and water from a boiler and steam pipes, etc., the water-glass method may be satisfactorily employed. This consists of shutting off all the feed valves (which must be known to be tight) and the main feed valve, thereby stopping absolutely the entrance or exit of water at the feed pipes to the boiler; then maintaining the steam pressure (by means of a very slow fire) at a fixed point, which is approximately that of the working pressure, and observing the rate at which the water falls in the gage glasses. It is well, in this test, as in other work of this character, to make observations every ten minutes, and to continue them for such length of time that the differences between successive readings attain a constant rate. In many cases the conditions will have become constant at the expiration of fifteen minutes from the time of shutting the valves, and thereafter the fall of water due to leakage of steam and water become approximately constant. It is usually sufficient, after this time, to continue the test for two hours, thereby obtaining a number of half-hourly periods. When this test is finished, the quantity of leakage is ascertained by calculating the volume of water which has disappeared, using the area of the water level and the depth shown on the glass, making due allowance for the weight of one cubic foot of water at the observed pressure."

The vital importance of a proper method of determining the steam used by the nozzles is best shown by giving some indication of the amount of steam that is being used by them in practice.

I have already given (p. 45) some data on this point, and in my experience, the average consumption is about 6·5 per cent. of the evaporation of the plant. Of the 400 plants tested, 153, that is 38 per cent., were fitted with steam nozzles, and the figures for each of these 153 tests are given in the columns of figures on pages 104-7.

With regard to the method to be used for determining the amount of steam used by steam jets, in the International Code I suggest the alternatives of a steam meter, or a surface condenser.

The only matter for criticism on this point in the American "Mechanicals" Code is that it does not make the use of steam meters compulsory, and allows alternative empirical methods, but the "Civils" Code does not allow steam meters at all. Steam meters will be dealt with more particularly on page 131, but they are especially convenient for determining with great accuracy (say to 1 per cent. since the demand is steady) the amount of steam used by nozzles, when these nozzles are all fed from one main supply pipe.

I would recommend strongly, as the ideal arrangement for a modern boiler plant, that the steam pipes be so designed that the whole of the auxiliary steam of the plant be passed through one auxiliary steam main pipe, as a branch from the main steam pipe over the boilers. On this auxiliary pipe should be installed a steam meter, which would thus give a continuous record of all the auxiliary steam. Also, because the amount used by steam nozzles is much the greatest and requires special watching, I would recommend further that all these nozzles be supplied by one pipe branching from this auxiliary steam main pipe, and on this pipe a second steam meter be installed.

Job Number.	Industry.	Method of Firing.	Number of Boilers.	Evaporation Per Boiler Per Hour, Lbs.	Net Working Efficiency of Plant After Deducting Steam or Power Used Auxiliary to Production of Steam.	Per Cent. Steam Used by the Jets.
345	Explosives	Mechanical	6	5861	48·78	21·4
267	,,	,,	2	5915	53·81	17·60
393	Jute mill	,,	2	2848	40·81	17·20
356	Colliery	Hand	2	3173	47·79	15·25
394	,,	Mechanical	7	4343	40·77	15·10
355	Paper mill	,,	3	5144	47·91	13·80
245	,, ,,	,,	3	4311	55·14	13·50
365	Hosiery manufacturers	,,	2	2838	46·88	12·25
154	Explosives	,,	15	6533	57·39	11·35
325	Engineering	Hand	2	4761	50·33	10·90
334	Paper mill	,,	5	4995	49·77	10·80
167	,, ,,	Mechanical	2	6583	59·40	10·40
371	Colliery	Hand	7	9728	46·47	10·30
295	,,	,,	6	6108	52·00	10·30
375	Pottery	,,	2	1698	45·97	10·20
231	Woollen mill	Mechanical	2	7002	55·97	10·00
376	Paper mill	,,	3	5408	45·94	9·60
313	Cotton yarn dyeing	,,	1	5393	50·94	9·60
389	Paper mill	Hand	1	2970	42·33	9·58
64	Cotton mill	Mechanical	1	3929	66·[illegible]	9·40
76	Explosives	,,	5	5933	65·58	9·25
259	Woollen mill	,,	4	6316	54·50	9·00
346	Engineering	Hand	1	5404	48·64	9·00
360	Paper mill	Mechanical	2	5601	47·46	8·90
286	Colliery	Hand	6	3561	52·60	8·88
338	,,	Mechanical	8	6229	49·35	8·64
66	,,	Hand	3	4294	66·30	8·60
88	Woollen piece dyeing	,,	2	6126	64·87	8·50
130	Calico printing	,,	4	4291	62·14	8·50
33	Explosives	Mechanical	8	6363	69·13	8·36
382	,,	Hand	5	4123	44·80	8·07
367	Colliery	,,	3	4249	46·73	8·06
156	Explosives	Mechanical	3	7382	59·92	8·00
268	Colliery	Hand	3	3813	53·80	8·00
366	Chemical manufacturers	Mechanical	4	2990	46·85	8·00
359	Colliery	Hand	9	4297	47·50	7·90
230	Glue manufacturers	,,	2	3071	56·01	7·88
275	Colliery	,,	3	4483	53·25	7·76
308	Paper mill	,,	2	4699	51·36	7·73
344	,, ,,	Mechanical	2	6431	48·81	7·60
385	Glue manufacturers	Hand	2	4879	44·12	7·60
244	Colliery	Mechanical	7	4450	55·15	7·50
10	Explosives	,,	16	4347	76·11	7·47
328	,,	,,	9	4955	50·11	7·30

Job Number.	Industry.	Method of Firing.	Number of Boilers.	Evaporation Per Boiler Per Hour, Lbs.	Net Working Efficiency of Plant After Deducting Steam or Power Used Auxiliary to Production of Steam.	Per Cent. Steam Used by the Jets.
53	Calico printing . . .	Mechanical	4	6769	60·14	7·30
69	Woollen piece dyeing . .	,,	3	7737	65·96	7·20
51	Engineering . . .	,,	3	5946	67·07	7·02
312	,, . . .	Hand	2	4530	50·95	7·00
340	Flour mill	,,	1	4585	48·98	6·90
283	Residential mansions . .	,,	2	3474	52·69	6·84
98	Colliery	,,	8	5000	63·98	6·65
87	Explosives	Mechanical	13	7401	64·98	6·60
225	Glue manufacturers . .	Hand	3	2754	56·19	6·50
129	Woollen mill . . .	Mechanical	4	6915	62·21	6·50
48	,, ,, . . .	,,	2	6714	67·23	6·50
390	Colliery	Hand	5	5852	42·33	6·40
347	,, ...	,,	5	4331	48·44	6·40
335	Flour mill	Mechanical	2	3554	49·46	6·31
318	Cotton piece dyeing . .	Hand	2	4157	50·66	6·30
62	Chemical manufacturers .	Mechanical	3	5945	66·40	6·25
307	Engineering . . .	,,	4	4211	51·39	6·02
235	Woollen mill . . .	,,	4	7357	55·74	6·00
160	,, ,, . . .	Hand	2	3159	59·73	6·00
269	Hosiery manufacturers .	Mechanical	3	6046	53·74	5·95
357	Colliery	Hand	3	4869	47·67	5·90
96	Tannery	,,	1	8805	64·15	5·80
109	Colliery	,,	6	6341	63·17	5·75
190	Explosives	Mechanical	4	7702	57·78	5·60
336	Glue works	,,	4	2940	49·42	5·58
330	Food products . . .	Hand	2	3731	50·04	5·50
243	Engineering . . .	,,	1	4836	55·19	5·50
38	Cotton piece dyeing . .	Mechanical	3	6421	68·47	5·40
271	Paper mill	Hand	3	4274	53·47	5·39
144	Dyeing and cleaning . .	Mechanical	7	6216	60·86	5·30
181	Paper mill	,,	2	3368	58·33	5·30
63	Colliery	Hand	3	8035	66·39	5·17
158	Explosives	,,	1	6136	59·82	5·00
223	Dyeing and cleaning . .	Mechanical	4	6601	56·30	4·97
254	Cotton piece dyeing . .	,,	3	6255	54·96	4·93
12	,, yarn ,, . .	,,	4	7350	74·05	4·90
379	Colliery	Hand	2	3895	45·60	4·80
256	,, ...	,,	3	4963	54·73	4·80
215	Paper mill	,,	2	4798	56·65	4·80
91	Explosives	Mechanical	1[illegible]	6927	64·74	4·52
273	Paper mill	Hand	2	7951	53·29	4·47
395	Hosiery dyeing . . .	Mechanical	2	2212	40·06	4·47
291	Cotton yarn dyeing . .	,,	2	5754	52·17	4·40
118	Tannery	Hand	2	4167	62·86	4·35

Job Number.	Industry.	Method of Firing.	Number of Boilers.	Evaporation Per Boiler Per Hour, Lbs.	Net Working Efficiency of Plant after Deducting Steam or Power used Auxiliary to Production of Steam.	Per Cent. Steam Used by the Jets
55	Paint manufacturers . .	Hand	1	4982	66·78	4·50
107	Woollen mill . . .	Mechanical	3	6073	63·25	4·30
186	,, ,, . . .	Hand	2	4486	50·96	4·20
67	Special textile . . .	Mechanical	6	6144	66·23	4·20
240	Aniline dye manufacturers .	Hand	4	4757	55·34	4·20
211	Paper mill	,,	6	7326	56·76	4·20
303	Woollen mill . . .	Mechanical	2	5789	51·68	4·12
79	Cotton mill	Hand	2	8372	65·44	4·10
23	Colliery	,,	5	9381	71·84	3·97
226	Explosives	,,	4	7716	56·18	3·97
294	,, ...	Mechanical	2	4463	52·09	3·92
249	Woollen mill . . .	,,	2	3598	55·05	3·80
104	Cotton mill	Hand	4	3618	63·49	3·80
125	Paper mill	Mechanical	6	5366	62·47	3·80
368	Colliery	,,	7	4907	46·66	3·80
229	Dyeing and cleaning . .	,,	5	5071	56·03	3·80
343	Heavy inorganic chemicals .	,,	3	2555	48·88	3·50
306	Dyeing and cleaning . .	,,	3	3182	51·51	3·50
200	Woollen mill . . .	,,	1	7463	57·37	3·50
170	Hosiery ,, . . .	,,	3	4376	58·91	3·50
198	Cotton piece dyeing . .	Hand	2	5418	57·43	3·50
77	Paper mill	,,	5	6536	65·57	3·50
80	Dyers and cleaners . .	Mechanical	4	5316	65·41	3·50
57	Explosives	,,	16	9528	66·74	3·47
317	Colliery	Hand	6	5590	50·78	3·40
360	Linen mill	,,	4	3626	51·41	3·40
213	Woollen mill . . .	Mechanical	2	3167	56·70	3·40
70	Cotton mill	,,	2	4305	65·95	3·40
2	Cotton yarn dyeing . .	,,	2	11456	80·09	3·25
16	Dyeing and cleaning . .	Hand	2	5093	73·26	3·20
238	Hat manufacturers . .	Mechanical	1	7457	55·45	3·20
133	Woollen mill . . .	,,	3	4659	61·76	3·20
159	Colliery	Hand	10	5586	59·76	3·18
124	Woollen mill . . .	Mechanical	3	6382	62·53	3·10
14	Food products . . .	Hand	5	7652	73·96	3·10
183	Colliery	Mechanical	2	8487	56·93	2·96
351	Cotton piece dyeing . .	,,	3	3257	48·11	2·75
82	Cotton mill	,,	3	8193	65·25	2·75
358	Colliery	Hand	4	3472	47·50	2·70
279	Woollen mill . . .	Mechanical	2	3073	52·83	2·70
108	Dyeing and cleaning . .	,,	4	4081	63·20	2·70
18	Engineering . . .	Hand	4	7609	73·02	2·60
363	Woollen mill . . .	Mechanical	2	3016	47·02	2·60
27	,, ,, . . .	Hand	6	4161	70·10	2·50

Job Number.	Industry.	Method of Firing.	Number of Boilers.	Evaporation Per Boiler Per Hour, Lbs.	Net Working Efficiency of Plant after Deducting Steam or Power Used Auxiliary to Production of Steam.	Per Cent. Steam Used by the Jets.
304	Woollen mill	Mechanical	5	6037	51·66	2·50
214	Cotton mill	,,	5	7557	56·66	2·50
169	Lace mill	Hand	2	5115	59·01	2·50
173	Woollen mill	Mechanical	2	7062	58·62	2·50
164	Hat manufacturers	,,	1	8734	59·54	2·50
220	Explosives	Hand	1	4165	56·44	2·49
252	Paper mill	,,	1	2976	54·98	2·48
311	,, ,,	Mechanical	1	7906	51·03	2·25
197	Engineering	,,	2	4735	57·47	2·10
4	Cotton mill	,,	2	9190	79·66	2·10
352	Colliery	Hand	5	4716	48·09	2·00
369	Explosives	,,	1	673	46·65	2·00
222	Food products	,,	2	1786	56·32	1·90
41	Colliery	Mechanical	1	12900	68·24	1·70
56	Woollen mill	,,	1	4659	66·75	1·50
20	Paper mill	,,	2	8059	72·11	1·30
370	Colliery	Hand	10	5679	46·52	1·00
266	Soap manufacturers	,,	2	3480	53·86	1·00
189	,, ,,	,,	2	2213	57·82	1·00
288	Woollen mill	Mechanical	2	7054	52·55	0·55
85	Cotton piece dyeing	,,	1	5057	65·06	0·50

For ordinary testing purposes the objection to the steam meter is that the steam nozzles are almost always supplied by a separate small pipe from each boiler, a most wasteful and unscientific method, which makes it difficult to determine the amount of steam used. Consequently, even if only two or three boilers are tested, the steam meter has to be coupled up to each boiler in turn, a very troublesome proceeding, although when once connected, this method is decidedly the best. In testing the 400 boiler plants, I have used the surface condenser method, and have devised for the purpose the apparatus illustrated in Fig. 17, and in the photograph of Fig. 18.

This apparatus has been in use for many years, and found to be most satisfactory.

In Fig. 17, A is a sheet-iron cylinder, water-jacketted,

with bolted lid B. The steam jet appliance, nozzles, pipes, etc., is detached from the furnaces of say one boiler, and

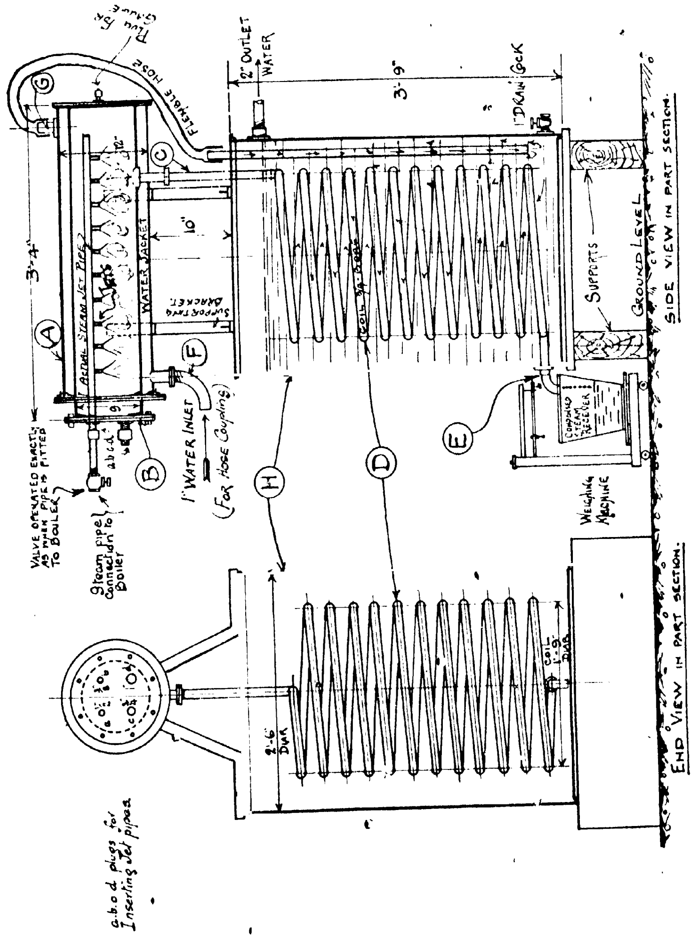

FIG. 17.—Surface condenser type of apparatus designed for determining the amount of steam used by steam jets.

placed bodily inside the cylinder A, being attached by a short pipe to coupling *a*, *b*, *c*, *d*, as most convenient, in the lid B. The steam jets are then connected to the boiler, the whole

FIG. 18.—Surface condenser type of apparatus designed for determining the amount of steam used by steam jets. Photograph showing apparatus coupled to boiler jets for test.

[To face p. 108.

apparatus being stood in the firehole close up against the boiler, so that the steam is blowing through the nozzles in the cylinder A exactly as it does when attached to the boiler furnace. The steam then blows down through the pipe C and through the coil D, open to the air at E. A continuous flow of cold water enters the jacket by the pipe F and leaves by the pipe G, and then flows into the large cooling vessel H. As a consequence the steam from the nozzles is condensed, and runs out at E, where it is weighed.

In working the apparatus, the valve on the steam supply to the nozzles is opened the same as usual, and as soon as a steady stream of condensed water is issuing from E, the test is carried out at half-hourly intervals by putting under the flow at E a weighed bucket at the half-hour by the clock, and collecting all the condensed water for weighing until the next half-hour. In this way numerous tests can be carried out, under any different conditions as regards the amount of turn of the steam supply valve, boiler pressure, etc.

One method (which is not to be recommended) that has been used to determine the amount of steam used by the nozzles is to place the nozzles in a weighed amount of cold water, and to pass in the steam for a given time, so that the water does not get hot enough to lose weight by giving off steam. The increase in weight then represents the amount of steam passed by the nozzles, but there is some difference of opinion as to whether the same amount of steam issues from the nozzles in the air under the furnace as it does when immersed in cold water.

The "Civils" Code also mentions the method of having one separate boiler devoted to supplying only the steam nozzles, and measuring the amount of water evaporated in this boiler to determine the steam produced. This, in my opinion, is not only quite unnecessary, but means also in most cases altering all the pipe circuits for the steam nozzles, as already described. If we are going to go to all this trouble, the steam meter is obviously the best method. Further, it

must be remembered that the efficiency of the auxiliary boiler plant may be different.

(4) *Mechanical Draught.*—This is also an important item, as mechanical draught may take anything from say 1 to 3 per cent. of the production. The typical installation of induced draught driven by direct coupled high-speed non-condensing engine absorbs about 6 h.p. per "Lancashire" boiler, 30 × 8 ft., and the consumption of the engine is about 35 lbs. of steam per i.h.p., corresponding to an evaporation of 215 lbs. per hour, or say, in averages, 2·75 per cent. of the production. In most cases it is sufficiently accurate to calculate the i.h.p. of the engine under average conditions in the ordinary way, but in special cases the actual steam consumption can be determined by condensing the exhaust steam or by a steam meter. If the exhaust steam is used to heat the feed-water, this heat added to the plant must of course be deducted in calculating the steam taken by the engine. When the fan is electric driven, the power can of course be obtained easily, but it must be calculated back to steam production of the plant, as if the current was generated on the spot. If the current is purchased from outside sources the cost must be calculated in the terms of coal.

It is very difficult to get the figure for the h.p. when the fan is driven from a line shaft, a bad practice in any case, and often the only way is by taking all the details of the fan, revolutions per minute, size, etc., and obtaining the h.p. from a similar fan driven by steam engine or motor.

(5) *Various Other Uses of Auxiliary Steam.*—There are various other points at which auxiliary steam or power may be used, such as the boiler feed pumps, economiser scraper engine, water-softening plant, electrolytic processes for the prevention of corrosion, and so on, and in each case the actual steam taken can be calculated without trouble on the same general lines, and added to the total amount of auxiliary steam. As will be seen, all these items added up together make a very formidable figure, and place an entirely different

complexion on the figures for the real net working efficiency of a boiler plant.

10. **Lbs. of Water from and at 212° F. per 1,000,000 B.Th.U.**—Both Codes give the figure for the lbs. of water per lb. of coal, and also the lbs. of water "from and at 212° F." per lb. of coal. This is, however, not sufficient, and I suggest to be included in the International Code a new and additional figure, namely, *lbs. of water from and at 212° F. per 1,000,000 B.Th.U.* It is of course little use to give merely the figure of lbs. of water evaporated per lb. of coal, since the temperature of the feed-water going into the plant may be at a temperature of anything from 32° to 212° F., and each 11° F., means a difference of approximately 1 per cent. in the coal bill. Both Codes get over this difficulty by calculating the evaporation "from and at 212° F.," that is, taking the evaporation of water per lb. of coal if the feed-water was always 212° F. This, however, still leaves untouched the other and equally important error, namely, *the heating value of the fuel*, which may vary from 7500 to 14,500 B.Th.U. per lb. The mere figure, as given in the codes, of the evaporation "from and at 212° F." means, therefore, very little.

For many years I have calculated accordingly the figure "lbs. of water from and at 212° F. per 1,000,000 B.Th.U.," which obviates both these difficulties, and I suggest that this new figure be included in the International Code.

11. **Various Minor Points.**—

(*a*) Both Codes insist upon reading the barometer during a boiler trial, so as to get the absolute steam pressure. Thus in the "Civils" Code (p. 78, line 34) is stated :—

"This (the absolute pressure) is obtained by adding the atmospheric pressure to the gauge pressure."

It seems to me to be a waste of time to read the barometer, and for all the difference it makes in the calculations, the absolute pressure may just as well be taken as 15 lbs. plus the gauge pressure. It certainly seems curious for the "Civils" Code to insist on including barometer readings, and

yet at the same time, as already seen, taking an arbitrary figure of 0·48 for the specific of superheated steam, irrespective of its temperature.

(*b*) The new figure for the latent heat of steam is 970·8, which is included in the American "Mechanicals" Code. In the "Civils" Code, however, the old figure of 966 is used as follows (p. 86):—

"Line 48 is line 47 multiplied by the evaporation factor, and the evaporation factor is equal to the total heat required to evaporate a pound of steam under boiler conditions, divided by 966, *i.e.*, it is equal to $\frac{H_1 - h_0}{966}$."

In the International Code 970·8 should be adopted.

(*c*) As regards temperature measurements ("Civils" Code, pp. 64-67), it is not necessary to fill the sockets with mercury, as thick oil will do just as well up to 500° to 600° F., and it is not very convenient to take flue gas temperatures up to 600° F. with mercurial thermometers, if only because these are so fragile, even when in armoured cases. In the International Code I would suggest a list being given of approved resistance and thermo-electric pyrometers, which are much more suitable for boiler testing work.

(*d*) The "Civils" Code (p. 37) recommends a most remarkable implement as an aid to boiler plant testing, namely, "a tool (Fig. 19) for gauging the thickness of the fire in the grate," illustrated as follows:—

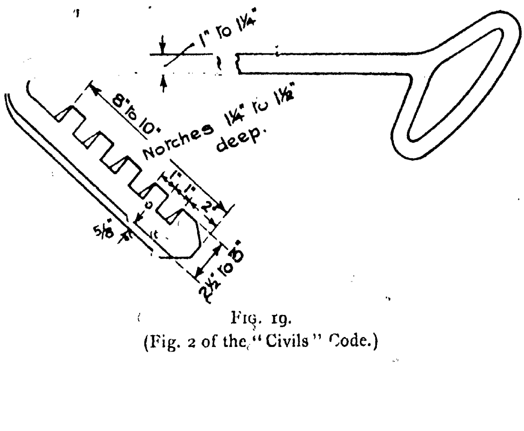

FIG. 19.
(Fig. 2 of the "Civils" Code.)

The Committee who drew up the "Civils" Code seem to have been much worried as to possible inaccuracies due to different amounts of coal being in the fires, at the commencement and at the end of the test. It is quite possible, of course, if a boiler fire is filled up with coal at the beginning of the trial, and allowed to burn empty at the end, that a considerable error —several cwts. of coal per "Lancashire" boiler—will creep in, and the plant will appear to be doing better than is actually the case. The solution of this difficulty is, however, merely the elementary one of looking at the fires when commencing, and having them the same at the end, and anyone with any common sense at all will not be in error more than say 1 cwt., equal to about 0·5 per cent. on the weight of the coal. It is quite easy to have an error as large as this in merely weighing the coal. Such simple methods, however, will not do for the "Civils" Code, even if the fact that 10 to 20 per cent. of the steam produced by the plant being blown away by steam nozzles is regarded as of no importance.

On page 9 of the Code we have:—

"In most cases the principal observer will be able to measure the thickness of fuel to within 1 in. As the error may be in opposite senses at the beginning and ending of a trial, it may amount to the weight of a layer of fuel 2 ins. thick. If C is the weight of green coal, which will form 1 cub. ft. of incandescent fuel, the total error should not exceed $C \times A \times \frac{2}{12} = \frac{CA}{6}$ lbs. Therefore if W is the number of lbs. of fuel per hour, A the square feet of grate covered by fuel, when its thickness is measured, and n the percentage of error admissible, the trial must last $\frac{100CA}{6nW}$ hours. C may be taken as 20 lbs. for large coal and 30 lbs. for small slack. In making use of this formula, however, it is necessary to have some regard to the quality as well as the size of the fuel. When it contains much dirt or makes a pasty clinker, the bars, if not self-cleaning, have to be cleaned at short intervals by the firemen, and at each cleaning there is loss of heat and combustible matter. The duration of the trial and the times

of cleaning should therefore be so arranged as to give this loss the same average value that it would have if the trial were indefinitely prolonged. For instance, if the fuel were such as to make cleaning necessary every 4 hours, it would be unfair to make a 5-hours' trial; 8 hours would be the proper time; or, if it were not possible to have the trial longer than 5 hours, a more accurate result would be obtained by working for 4 hours only and cleaning the fire-grates only once."

Accordingly, we are recommended to use a "tool," a huge steel poker, 1 to 1½ in. diameter, and presumably 8 or 9 ft. long, as illustrated in Fig. 19. When the trial starts we have apparently (p. 13) to open the fire-doors, and in the blinding heat, rummage about in each fire taking the thickness at various places, and recording the same. This procedure is to be repeated at the end of the trial, and presumably a calculation made for different thicknesses of the fires before and after. It is not stated whether another calculation will also have to be made to compensate for the loss of efficiency caused by having the fire-doors open and allowing cold air to enter whilst the measurement is in progress. Taking, for example, the case already mentioned, of a plant of thirty-two "Lancashire" boilers, do we understand that before commencing a test, which can be of 3 hours' duration ("Civils" Code, p. 9), it is necessary to insert this "tool" in sixty-four different furnaces? I should estimate that each determination would take at least 4 minutes, and that after about four furnaces one man would be exhausted, so that with relays of men, the measurement of the thickness of the sixty-four fires would take, say, 4 to 5 hours, or longer than the duration of the test allowed. Or perhaps we have in such cases to have a whole battery of "tools". It would be very interesting to know if any member of the "Civils" Committee has ever tried to measure the thickness of a fire with the "tool," which he joins in recommending for this purpose.

(*c*) On page 7 of the "Civils" Code there is stated :—

"If it is desired to ascertain whether cold water is lodging in the bottom of Lancashire or other boilers of similar type, a

horizontal tube should be screwed into the front part of the boiler, or preferably the front manhole door. The stopped end of the tube should be carried sufficiently far back to avoid the possible lodgment of cool water at the front end which may arise from the bottom flue not extending right up to the front of the boiler."

What this means is not clear.

12. **The Method of Calculating the Results.**—The methods given in both the Codes for calculating the results of a boiler test are, in general, so completely involved and complicated, that it is impossible to criticise them in detail in any reasonable length. It seems to me that the fundamental error in these methods is the attempt at all costs to evolve a " heat balance sheet," which, in my opinion, is not necessary, and in any case is inaccurate.

In dealing with this difficult subject, I propose, for the sake of simplicity, to describe first the method of calculation which I suggest be embodied in the International Code. I hope to show that this method is quite simple and practical, that there is no particular mathematical knowledge required at all, and that the complete figures of an official trial can be worked out in twenty minutes on first principles without any empirical formulæ. In this connection the "Civils" Code especially falls into the error of giving ready-made formulæ and symbols, which means that most engineers use these in a rule-of-thumb way without understanding the principles involved, and errors are bound to result.

Taking again the specimen test results on page 146, the essential figures, apart from simple averaging, division, etc., which require no consideration, are that 105,328 lbs. of water at 121° F. are evaporated on the plant, the average temperature after the economiser being 296° F. and the temperature of the superheated steam averaging 475° F. with 147 lbs. gauge pressure (162 lbs. absolute). At the same time, 13,960 lbs. of coal with a net calculated heating value of 11,715 B.Th.U. per lb. are burnt, and the total amount of auxiliary steam (or power expressed as steam) is 13,639·9 lbs. (12·95 per cent.).

The essential figure required, to which all other figures are merely subsidiary, is the net working efficiency of the complete steam generation plant, that is to say, for every 100 lbs of fuel delivered to the plant, how many lbs. of fuel are actually used for the production of useful steam, and how many lbs. are wasted. Thus, when we say that the average net working efficiency of the boiler plants of Great Britain is 60 per cent. we mean that out of every 100 lbs. of coal burnt, 60 lbs. are used to produce useful steam and 40 lbs. are wasted in radiation, imperfect combustion, leaky brickwork, loss of heat in the ashes, auxiliary steam used on the boiler plant itself and so on. We have, therefore, in the calculations, to determine the actual number or British Thermal Units of heat given to the plant in the fuel, and the actual number of British Thermal Units of heat coming out of the plant as useful steam.

By the steam tables we find that the total heat required to convert 1 lb. of water at 32° F. into steam at 162 lbs. absolute is 1194·5 B.Th.U. The feed-water entering the plant is, however, 121° F., that is to say, less heat is required than 1194·5 to convert 1 lb. of water at 121° F. to steam at 162 lbs. absolute.

The "Civils" Code assumes that the specific heat of water is the same at all temperatures, that is to say, the British Thermal Unit of Heat is the amount of heat required to heat 1 lb. of water 1° F. irrespective of the initial temperature of the water. Or, in other words, that it takes the same amount of heat to raise the temperature of 1 lb. of water from, say, 32° to 33° F. as it does to raise it from, say, 200° to 201° F., and therefore the amount of heat required to convert 1 lb. of water at any initial temperature (t) above 32° F. into steam at a given pressure can be got by subtracting 32 from (t), calling the figure B.Th.U., and then subtracting it from the total heat figure from 32° F. In the example, therefore, according to the "Civils" Code, the total heat from 121° F. is 121 − 32 = 89, subtracted from 1194·5 = 1105·5. This, of course, is erroneous, and the specific heat of water is different for every

° F. The heat required to raise 1 lb. of water from 32° to 33° F. is a maximum, and the specific heat very slightly falls with the temperature to about 130° F. and then rises again as shown on the curve, Fig. 20. Thus, for the given example of 121° F. the amount of heat to be subtracted is not 121 − 32 = 89 B.Th.U., but actually 88 B.Th.U.

This is not of course a very serious matter, but as it is no more trouble to be accurate, I suggest that in the International

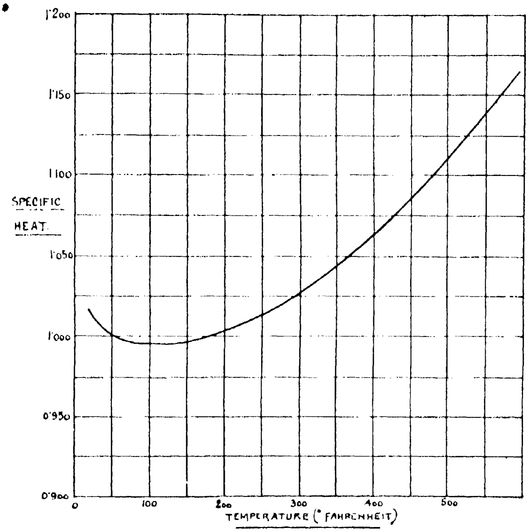

FIG. 20.—Curve showing the specific heat of water at different temperatures.

Code the formula $h = 1{\cdot}017\,t - 35$ is used in calculating the heat (h) at a given temperature (t) to be subtracted from the total heat at 32° F. This formula is quite simple, and gives a very near approximation indeed to the mathematical curve. Thus at 121° F.

$$\begin{aligned} h &= (1{\cdot}017 \times 121^\circ \text{ F}) - 35 \\ &= 123{\cdot}057 - 35 \\ &= 88 \text{ B.Th.U} \end{aligned}$$

which subtracted from 1194·5 gives the figure of 1106·5.

In the same way for the economiser calculation, the total heat from 296° F. is (296 × 1·017 − 35) = 266·0 B.Th.U., so that the total heat from 296° F. is 1194·5 − 266 = 928·5 B.Th.U. Also, the steam is superheated to 475° F., that is 475° − 364·4° (saturation temperature from the steam tables) = 110·6° F., and from Knoblauch and Jakob's Superheat Tables the specific heat of steam at 475° F. and 162 lbs. absolute is 0·54. 110·6 × 0·54 = 59·7, so that the amount of heat required to raise 1 lb. of water at 121° F. to steam at 162 lbs. absolute, and superheat it to 475° F. is 1106·5 + 59·7 = 1166·2 B.Th.U. This gives us all the figures necessary for the amount of heat absorbed by 1 lb. of water under the different conditions of the boiler, economiser and superheater.

In the test 105,328 lbs. of water required 15,960 lbs. of coal, so that 1 lb. of water $= \dfrac{15960}{105328} = 0·15152$ lbs. of coal. Also, since the net heating value of 1 lb. of coal is 11,715 B.Th.U., 0·15152 lbs. of coal will contain 11715 × 0·15152 = 1775·0 B.Th.U., which represents, therefore, the actual heat put into the plant. The net percentage of heat taken by the different essential portions of the plant is now as follows:—

(1) *Boiler Only.*—Since the amount put in the firehole was 1775·0 B.Th.U., and that absorbed by the boiler is 928·5 B.Th.U. (*i.e.*, heating the water from 296° F. to saturation at 162 lbs.), the percentage of heat in the original coal absorbed by the boiler is $\dfrac{928·5 \times 100}{1775} = 52·31$ per cent.

(2) *Economisers Only.*—Again, since the heat put in the firehole is 1775·0 B.Th.U., and that abstracted by the boiler and economisers is 1106·5 B.Th.U. (*i.e.*, heating the water from 121° F. to saturation at 162 lbs.), the percentage of heat absorbed by the boiler and economiser is

$$\frac{1106·5 \times 100}{1775} = 62·33 \text{ per cent.}$$

Since the boiler was 52·31 per cent. the economiser only will be 62·33 − 52·31 = 10·02 per cent.

(3) *Superheater Only.* — Again, as before, taking the original figure of 1775·0 B.Th.U., the amount of heat absorbed by the boiler, economiser and superheater is 1166·2 B.Th.U. (*i.e.*, heating the water from 121° F. to saturation at 162 lbs. and superheating to 475° F.), the percentage of heat absorbed by the boiler, economiser and superheater is

$$\frac{1166{\cdot}2 \times 100}{1775} = 65{\cdot}70$$

per cent., and as the figure for the boiler and economiser together is 62·33 per cent., the figure for the superheater only is 65·70 − 62·33 = 3·37 per cent.

(4) *Net Working Efficiency.*—We have seen, therefore, that for 100 lbs. of coal put in the firehole 52·31 are absorbed by the boiler, 10·02 by the economiser, and 3·37 by the superheater, a total of 65·70, the other 34·30 parts being wasted by radiation, inefficient combustion, leaky brickwork, etc. This figure of 65·70 per cent. is not, however, the net working efficiency of the plant, because although 65·70 per cent. of the heat of the coal is absorbed by the boiler, economiser and superheater, this heat is not given out of the plant to the factory as steam. 12·95 per cent. of it is taken up by the plant itself, as already seen, for steam jets, induced draught, boiler feed pump, etc. The real net working of the plant is therefore

$$\frac{65{\cdot}70 \times 12{\cdot}95}{100} = 8{\cdot}50 - 65{\cdot}70 = 57{\cdot}20 \text{ per cent.}$$

(5) *From and at* 212° *F. Calculation.*—In order to calculate the lbs. of water evaporated per lb. of coal, assuming the water was 212° F. (instead of actually 121° F.), all that is necessary to do is to multiply the lbs. of water at 121° F. per lb. of coal, that is, $\frac{105328}{15960} = 6{\cdot}60 \times 1106{\cdot}5$ (the total heat from 121° F. to saturated steam at 162 lbs.), and divide by the latent heat of steam (970·8). That is

$$\frac{6{\cdot}60 \times 1106{\cdot}5}{970{\cdot}8} = 7{\cdot}51 \text{ lbs. of water from and at } 212^\circ \text{ F.}$$

This figure can be checked by the "factors of evaporation" figure from any engineering pocket book.

To get the "evaporation from and at 212° F. per 1,000,000 B.Th.U.," if 7·52 lbs. from and at 212° F. are evaporated per lb. of coal, the heating value of which is 11,715 B.Th.U., then 11,715 B.Th.U. is equivalent to 7·52 lbs. and 1,000,000 is equivalent to $\frac{7 \cdot 52 \times 1{,}000{,}000}{11715} = 641 \cdot 9$..

(6) *Saving in Coal Bill Due to Economisers.*—In the gross efficiency figures, the boiler and economiser is 62·33 per cent. and the economiser only is 10·02 per cent., so that expressed as a percentage the saving in the coal bill is $\frac{10 \cdot 02 \times 100}{62 \cdot 33} = 16 \cdot 1$ per cent., which can also be checked by empirical tables found in most pocket books, or economiser makers' catalogues.

(7) *Saving in Coal Bill Due to Superheaters.*—In the same way the gross efficiency of boilers, economisers and superheaters is 65·70 per cent. and the superheater only 3·37 per cent., so that the saving in the coal bill due to the superheater is $\frac{3 \cdot 37 \times 100}{65 \cdot 70} = 5 \cdot 1$ per cent.

These figures are the essential ones for the true performance of any boiler plant. That is to say, for every 100 lbs. of coal put into the plant, 57·20 lbs. are being used to produce useful steam, the other 42·8 lbs. being wasted, 8·5 lbs. due to auxiliary steam and 34·3 parts to various losses not yet analysed.

One of the losses is radiation from the whole body of the plant. In my opinion, it is not essential to determine this experimentally, and I would not propose to include it as part of the International Code. It can, however, be determined if required by running a test on the plant for a number of hours, the longer the better, with the main steam pipes to the factory shut down and supplying just enough coal to the plant to maintain the full boiler pressure without blowing off. The amount of coal burnt in comparison with that of the full working trial will give the radiation loss, which may correspond to anything

from 5·0 to 10·0 lbs. for every 100 lbs. of coal taken by the plant. The "Civils" Code (p. 53, also p. 79) seems to regard this as an essential part of the test, but the method proposed, is not at all clear, and as far as can be made out, seems to apply to the boiler only, and not to the whole plant. Of course, the radiation loss should include the boiler, economiser, superheater and all accessories.

The other sources of loss are faulty firing, that is, excess or deficiency of air passing through the fires, cooling of the plant due to leakage of cold air, heat losses in the ashes, and insufficient heat absorption by the boiler, superheater and economiser, that is too high an exit temperature in the chimney base. The "Civils" Code, and to a lesser extent the American "Mechanicals" Code, get in to a terrible tangle in calculating these losses, and, in fact, approach the whole of the calculations on the assumption that these losses, and not the amount of heat put into the plant, are the most important part of the calculations. It is stated in the "Civils" Code (p. 5) that the measurement of the losses are "a valuable check on the accuracy of a trial," but my point is that in any case the loss figures are not accurate, even if they were necessary.

For example, we have in the "Civils" Code (p. 78, l. 23, pp. 80-85, ll. 39-40, p. 86, ll. 51, 52, 54, 55, 56, also pp. 88-90) the particulars dealing with the amount of heat passing away from the plant, and the heat carried away by the excess air, in half a dozen pages of complicated calculations. The basis is the full analysis of the flue gas (CO_2, CO, O and difference) to represent all the gases leaving the plant during the test, and then the calculation of this volumetric gas analysis to parts by weight. It is then assumed that all the carbon in the coal appears in the flue gas as CO_2 and CO, and following on a complete analysis of the coal for the percentage of carbon, hydrogen, etc., it is calculated how many lbs. of dry flue gases leave the boiler flues per lb. of fuel burnt. This calculation is based on dry flue gases, but

they are not dry as they contain, as already seen an enormous amount of water, equal to 8·95 times the weight of the hydrogen originally present in the fuel, together with the natural moisture, but making allowance for this we arrive at the figure for the weight of air drawn into the flues per lb. of fuel. By another calculation on the percentage of carbon, hydrogen, etc., in the coal burnt, the theoretical weight of flue gases is calculated, and in this way the excess air is determined. In order to try and reduce the labour of these calculations an empirical formula is recommended (p. 85), namely,

$$\frac{\text{Heat carried away by dry gases}}{\text{per lb. of fuel burnt}} = \frac{\text{Constant} \times a \times (T - t)}{C}$$

Where a = percentage of carbon by weight in the fuel after correction for unburnt material in the ash.

C = percentage of CO_2.

With regard to the constant, this is explained as follows :—

"The constant for flue gas at about 500° F. may be taken as 0·605 and the error will not exceed 1 per cent. on the heat balance, which is well within the limits of experimental error."

With regard to the question of the loss in heat in the hot ashes (p. 86, ll. 42, 42a), this is, in my opinion, a matter of little importance. The "Civils" Code has to assume that the temperature of the hot ashes as withdrawn from the fires is 2000° F. and the specific heat of the ashes is 0·3, and all these assumptions reduce the "heat balance sheet" to a farce. In order, therefore, to make this calculation for the heat passing up the chimney, we have to make a complete and laborious chemical analysis of the fuel, in addition to the heating value by the bomb calorimeter, an analysis of the ash, an analysis of the flue gases, and a whole series of complicated calculations, and the results when obtained are based largely on assumptions. I would suggest that in the International Code all this be cut out as not essential.

The information obtained by the CO_2 Recorder will give us without any trouble, by the curve, Fig. 8, a figure for the

loss in heat due to faulty firing, which is practically that obtained at so much expense and trouble by the method of the "Civils" Code.

Thus, for example, in the specimen trial the figure for CO_2 is 6·0 per cent., and by the curve this corresponds to 16 per cent. loss in coal, taking 14 per cent. as the maximum CO_2 obtainable in practice.

Another extraordinary feature of the "Civils" Code is that the whole of these laborious calculations have to be gone through all over again for the economiser, and yet a third time for the superheater. I am at a loss to understand what is the reason for suggesting that the economiser and superheater should be regarded, from the point of view of gas analysis, as separate from the boiler, and the essential figures for the economiser and superheater can be worked out in a few seconds by the method suggested on page 115. And to further add to the confusion, the "Civils" Code then proceeds to give (p. 80) an entirely fresh and empirical formula for calculating out efficiencies without the aid of steam tables, in spite of the fact that anyone can buy steam tables for a few pence, and the method suggested is admittedly not accurate.

PART III.

SUGGESTIONS FOR NEW FEATURES WHICH MAY BE ADDED IN THE FUTURE TO AN INTERNATIONAL CODE AS THE RESULT OF FURTHER DISCUSSION AND INVESTIGATION.

1. **The Question of the Use of a Special Factor, Depending on the Quality of the Fuel, to be Used in Calculating the Net Working Efficiency of the Plant.**—Up to the present time, in most boiler plant tests the efficiency has been calculated simply from the actual amount of heat present in the fuel, and no allowance has been made for different qualities of fuel, and for the different theoretical efficiencies possible.

For example, if one plant is using the finest washed nuts with, say, 3 per cent. ash and 14,000 B.Th.U. per lb., and another plant is using merely refuse coal with, say, 35 per cent. ash and 7000 B.Th.U. per lb., and no auxiliary steam is used in each case, the efficiency is calculated in the same way in both instances, that is, on the amount of heat actually present in the coal. Thus, the first plant may be working at 72 per cent. net working efficiency and the other at 59 per cent., and according to the methods of calculation generally adopted, the first plant is regarded as doing very much better than the second. Stated in this way the results are completely misleading, because the fact is ignored that with the good coal the price may be, say, £2 10s. per ton, and the possible efficiency 80 per cent., and with the inferior coal and the same amount of skill and attention, the efficiency can only be 65 per cent., but the price is £1 5s. per ton.

The reason is, of course, that with inferior coal the percentage of ash is so great that, even with mechanical stokers, it is not easy to prevent excess air passing through the fires, it is much more difficult to burn the coal with the evolution of radiant heat, and an excess of heat is lost in the ash.

This is, however, very unfair to the plant using inferior coal, both scientifically, as well as from a practical and business point of view. For example, to look at the matter in another way, take a case of a plant burning 200 tons a week of the inferior coal at 25s. per ton, with a net working efficiency of 59 per cent., and with an annual coal bill therefore of £12,500. If expensive coal of 14,000 B.Th.U. at £2 10s. per ton is substituted, it is quite true that the efficiency is increased to 72 per cent. and the amount of coal burned is only 163 tons per week, yet the net result of this is to increase the fuel bill of the factory from £12,500 to £20,375 per annum. According to the usual methods adopted, however, as in both the Codes, the plant is now doing better, in spite of the fact that the practical result would be to lose £7875 per annum! This, of course, is an absurdity, and I have in the past tried to get over this difficulty to some extent by always giving the cost of evaporation of 1000 gallons of water, although this has the defect that it is dependent on prices of fuel, which vary considerably in different neighbourhoods. I would suggest, however, that this item be included in the International Code. Some makers of appliances for steam generation understand the point very well, and many of the remarkable results that are published as having been obtained with various appliances will be found, on investigation, to be really due to the fact that especially good quality coal has been used. If such coal had been used on the original plant, the same results might have been obtained without the appliance at all.

Thus, it is a favourite method to take, for example, a hand-fired plant with natural draught, and simple fire-bars burning average coal of moderate price and quality, and to fit on some appliance to burn cheaper fuel with the object of showing a

saving. The only fair and reasonable method of proceeding is to burn the same quality of coal as before, and if further trials are carried out with cheap refuse coal or expensive good quality coal, then to have at the same time analogous trials with these coals on the plant as originally working. It is amazing the number of tests published that trust to the steam user to ignore these elementary facts. A given furnace stated, for example, to save, say, 30 per cent. of the coal bill, will be found on investigation to have been tested with cheap refuse coal, of which only a limited supply is available, as against average priced coal on the original plant. If, in the later case, the same refuse coal had been used, whilst the results might not perhaps have been as good as with the special furnace, the real saving would have been about 10 per cent. instead of 30 per cent. When this is pointed out the reply is usually, as I know from experience, that the test has been carried out according to the usual practice, and sufficient allowance has already been made in calculating the efficiency from the actual heat value. On pressing the point, however, refuge is then as a rule taken in the "Civils" Code, in which no allowance has been made for different qualities of fuel, although in the test in dispute no attempt has been made to carry it out according to this Code.

What is required is that there should be added to the ordinary calculated efficiency a further quantity X, which would vary according to the heating value and quality of the fuel. The value of X would be expressed as a curve, which I would suggest calling the *Standard Curve of Efficiency Correction for the Diminishing Heat Value of the Fuel*, so that the value of X would increase as the value of the fuel decreased. This would put all boiler plants on a real comparative basis, and give proper credit to the man who is burning a cheaper and inferior fuel, and doing a national service as well. Such a curve could only be obtained experimentally, and this I suggest would be one of the points of investigation for the International Committees.[1]

What would be necessary would be for, say, twenty or so thoroughly representative coals to be taken, from the highest to the lowest quality, and a complete series of experiments carried out under various conditions of steam generation on, say, "Lancashire," "Marine," and "Water-tube" boilers with, for example, (1) rated evaporation, (2) 20 per cent. overload, (3) 20 per cent., and (4) 50 per cent. below rated load, both with hand firing, and different types of mechanical stoker. If a whole series of trials were carried out in this way, on a well equipped experimental plant, sufficient data would be obtained to elaborate such a curve with a considerable amount of accuracy.

Based on the experience of over a thousand tests, I would suggest the curve as given in Fig. 21 (next page). I do not pretend that this curve is accurate, because, as already stated, it would need to be based on much experimental work, but it is of interest as illustrating the principle. Thus, in the Specimen Test, the value of X with coal of 11,715 B.Th.U. would be 5·0, and this would then be added to the figure of 59·4 per cent. for the net working efficiency. The result, 64·4 per cent., which would be called the C.D.H.V. net working efficiency (corrected for diminishing heat value). In the example just mentioned the plant with 14,000 B.Th.U. coal, and 72 per cent. efficiency, would have added the figure of 0·5, making 72·5 per cent. efficiency; and the plant with 7000 B.Th.U. and 59 per cent. efficiency would have the figure of 23·5, making 82·5 per cent. The latter plant would, therefore, be much the best by calculation, as it is in practice.

2. **Labour, Attendance, Repairs, Upkeep, Interest and Depreciation.**—Another difficulty is that of the cost of working the plant, quite apart from the fuel bill. If, for example, a plant of ten "Lancashire" boilers has only four men per shift looking after it, together with reduced labour at night, and a wage bill of, say, £20 per week, working on 60 per cent. efficiency, and the plant is then reorganised to work on an efficiency of 75 per cent., but the wage bill is increased to

£30 per week, this extra £500 per annum ought to be deducted in calculating the net result. In the same way, if

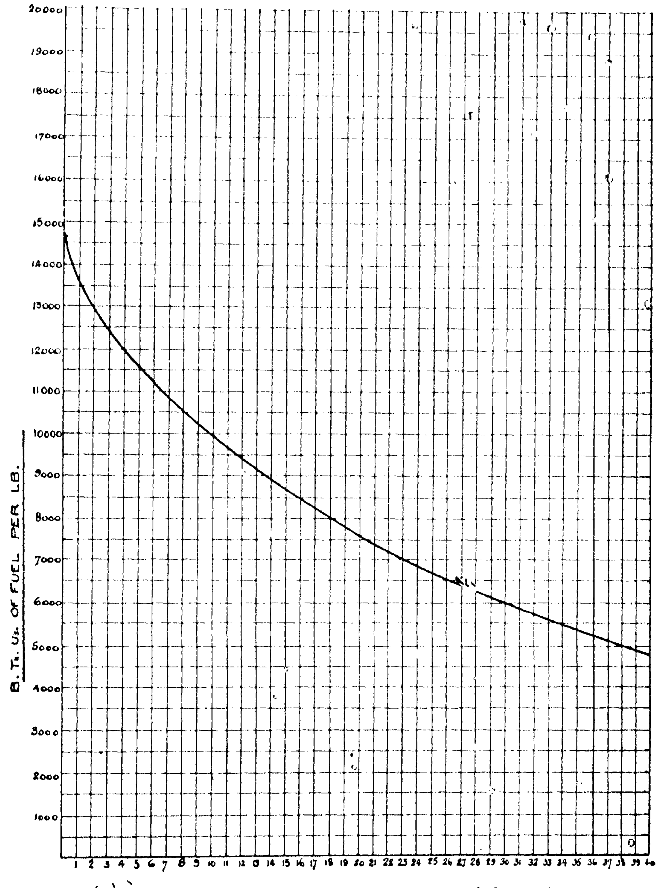

FIG. 21.—Suggested standard curve of efficiency correction for the diminishing heat value of the fuel (coal only).

many additional appliances and instruments are installed, so that the cost of repairs and upkeep is increased from, say,

£200 to £500 per annum, then this extra £500 should also be deducted.

In almost all boiler plant tests these considerations are ignored, and no instructions are given on the point in any code. This is particularly unfair in the reverse instance on a very large plant of, say, sixteen boilers, where mechanical stoking and mechanical coal and ash handling is installed. Twelve men per shift may have been working under hand conditions, and the installation of mechanical appliances throughout may save the labour of eight men, that is, several thousand pounds per annum in wages. It is unfair that this saving should not be added to the efficiency figures, since the steam or power used has been deducted.

There is also the question of interest on capital, and depreciation. A firm may have a boiler plant of ten "Lancashire" boilers which has cost complete, say, £25,000. If this plant is reorganised to improve the efficiency and a further £15,000 spent on economisers, water-softening plant, mechanical draught, mechanical stokers, instruments such as CO_2 Recorders, water meters, etc., then there must be deducted from the saving, interest on this £15,000 and depreciation on the new plant. If we take the interest as 6 per cent., and depreciation as 10 per cent., this corresponds to an annual sum of £2400, or, say, 1200 tons of coal to be deducted in calculating the real net saving, which makes a very substantial difference in the figures. This important practical point is also ignored in all boiler plant tests, and some of the published results of tests would look very different if such figures were included. I think that the whole question should also be investigated by the International Committees, but would suggest the following basis:—

In every case the cost of the labour, attendance, repairs, upkeep, interest and depreciation be calculated, and then expressed as equivalent tons of coal per annum. For example, if in a boiler plant of ten "Lancashire" boilers, burning 10,000 tons of coal valued at £20,000, the total cost was

£35,000, the interest at 6 per cent. and the depreciation at 10 per cent. would correspond to £5600 per annum, and the cost of labour, attendance and repairs was £2000, the total cost would be £7600, that is, 3800 tons of coal per annum or 38 per cent. of the coal bill. I would suggest that the final efficiency figure would then be the C.D.H.V. net working efficiency, less 38 per cent. of this figure, that is, if the C.D.H.V. was 85 per cent., the final figure would be $85 - 29{\cdot}75 \frac{(38 \times 85)}{100} = 55{\cdot}25$ per cent." Some such method as this would get over many practical difficulties, and bring into true perspective the real practical value of plant, machinery and appliances constituting a boiler plant, including all the important items of capital outlay, repairs and labour and attendance. It would do away also with the absurdity of a large boiler plant being worked at a very low evaporation so as to get a high efficiency. If, however, the interest and depreciation on the capital outlay of this large plant was included, the proper value of such a proceeding would then be apparent at once.

3. **Dust and Grit in Chimney Gases.**—In connection with the difficult question of recording the amount of black smoke, nothing is ever mentioned about dust and grit in the chimney gases, and this point is now becoming important since the modern power station practice is to have very short steel chimneys. Although there may be no smoke, the amount of such grit and dust given off can be easily a serious matter, as it is thrown out over a very restricted area. I am of the opinion that the International Committees should devise some standard method of testing chimney gases for dust and grit, so that this would be included in the International Code. One idea that suggests itself is to insert a bent pipe with an expanding vertical nozzle in the chimney base, so that the area of the nozzle could be made a standard proportion of the inside area of the chimney at this point (say 5 per cent.). The other end of the pipe would be connected to a metal box kept

by means of a small fan (hand or motor driven) at a standard suction (say 10 per cent.) above that of the chimney base. Consequently 5 per cent. of the chimney gases would be pulled through the box, which could be provided with baffles and a cloth bag to collect the solid material, which would then be weighed and expressed as so many ounces per hour, or by some other convenient term.

4. **Steam Meters.**—Another point for investigation by the International Committees is the question of using steam meters to measure the output of the plant instead of, or in addition to, the measurement of the water evaporated. The "Civils" Code does not mention steam meters at all, whilst, as already seen, the American Code permits their use for testing auxiliaries. There is no doubt that the logical method of determining the output of a boiler plant is to measure the useful steam actually passing into the factory, if only this could be done with sufficient accuracy. Steam meters have already been referred to on page 103 in connection with the measurement of auxiliary steam, and since this—in averages—is, say, 6 to 10 per cent. of the production, a steam meter is very satisfactory for the purpose. The matter is not, however, quite so easy when the total output and the net working efficiency of the boiler plant have to be calculated.

There is no doubt that the invention of a simple and reliable form of steam meter has been one of the most difficult problems in engineering. The steam may contain different amounts of water, and, if superheated, the temperature may vary considerably, whilst the amount of steam passing may fluctuate suddenly through a wide range, and there may also be a pulsating action. Further, as already stated, the steam often has a violent swirling motion in the pipe, so that it is very difficult to get a true figure for the average velocity. However, these difficulties have now in general been surmounted, and there is at present on the market seven different makes of steam meters.

Steam meters can be divided into two general classes.

The first consists of meters in which the whole of the steam passes through the body of the meter, as represented by the "Bayer" and "St. John" meters. In these meters a cone or disc is lifted off its seat according to the amount of steam passing, and a recording mechanism is actuated by this means.

The second class consists of meters in which a disc or plug is inserted in the steam pipe line, and connected to the recording mechanism. In the "British Thomson-Houston," "Curnon" and "Sarco" meters the disc or plug is a "Pitot" tube, whereas in the "Bailey" and "Kent" meters the principle is that of a "Venturi" tube. The amount of steam passing is proportional to a small difference of pressure shown either by these "Pitot' or "Venturi" tube devices, and this pressure varies from zero to say ¾ lb. per sq. in. In measuring this small pressure and expressing it as lbs. of steam passing in the pipe the "Bailey" meter uses a sealed cell floating in mercury, the "Curnon" and "Kent" meters a diaphragm, and the "British Thomson-Houston" and "Sarco" meters a modified "U" tube with float.

The makers of most of these meters claim an accuracy of 1 to 2 per cent., but the trouble seems to be that most meters are not as accurate when the passage of the steam is fluctuating. I think that, subject to further investigations, steam meters ought to be included in the International Code as a useful addition to the measurement of the steam output of the boiler plant.

PART IV.

DESIGN OF REPORT SHEETS FOR THE NEW CODE.

THE following is the design of "Report Sheets" I would suggest for use with boiler tests carried out according to an International Code. The explanation of each item, the exact method of carrying out the test and logging the results, say, every half-hour, and the working log sheets for actual use on the test itself will hardly need much description and it will not be necessary to include it in this book.

In general, however, the International Test Code Sheets I would suggest be divided into four main and distinctive groups in logical order, namely, (1) A General Description of the Whole Plant, (2) Particulars Relating to the Burning of Fuel, (3) Particulars relating to the Production of Steam, (4) Tabulated Results.

After the preliminary sheet, item (1), is a detailed description of every part of the plant in the natural sequence, commencing with the boilers, following through with everything relating to coal, that is, coal and ash handling plant, grates, control of firing, economisers, chimney flues and mechanical draught, then following with details relating to steam production, such as boiler feed-water, method of boiler feeding, measurement of feed-water, superheaters, measurement of steam output and steam pressure. This will give a complete account of the details of the equipment of the plant, and, in my opinion, it is much better to be embodied in the Test Sheets in this way.

Item (2) deals with all the particulars of the test relating to the fuel, namely, the description and quality of the fuel, the

analysis, the amount used, the particulars as regards the ash, flue gas temperatures, draught, flue gas analysis, and black smoke.

Item (3) deals in the same way in order with each item relating to the production of steam, namely, the amount of water evaporated, the temperature of the water, the steam pressure, the amount of superheat, and the auxiliary steam or power used for the production of steam.

Item (4) then gives the tabulated results, that is, the water evaporated per lb. of coal, "from and at," "from and at" per 1,000,000 B.Th.U., and the efficiency figures, that is, the net working efficiency of the plant, and the separate figures for the boiler, economiser and superheater. Also the cost for evaporation of 1000 gallons of water.

The last sheet is the "Long Check Test," giving the essential figures of the water evaporated, and the amount and analysis of the coal used.

The example given of a Report on these lines, with the figures of an actual test, will doubtless make the matter clear.

COMPLETE STEAM BOILER PLANT TEST REPORT.

(Test Carried out According to the International Steam Boiler Plant Test Code.)

GENERAL PARTICULARS.

(*a*) Boiler plant situated at . . .	Manchester.
(*b*) Name of plant	Main boiler plant (paper mill).
(*c*) Date of test	June 21-28, 1921.
(*d*) Duration of test	8·00 hours.
(*e*) Duration of long check test . .	168·00 hours.
(*f*) Test carried out by	— — —
(*g*) Test carried out in the presence of	— — —
(*h*) Object of the test	To find the performance figures for the present ordinary running from week to week.
(*i*) General remarks	The present summer load is roughly 10 per cent. less than the winter load.

GENERAL DESCRIPTION OF THE BOILER PLANT.

1. BOILERS.

(*a*) Type of boiler	"Lancashire".
(*b*) Number of boilers on the plant	3.
(*c*) Number of boilers used on the test	2.
(*d*) Chief dimensions . . .	30 × 8 ft.
(*e*) Heating surface per boiler .	1000 sq. ft.
(*f*) Maker	X.
(*g*) Date installed	One boiler 1910, two boilers 1914.
(*h*) Maker's rating of boiler output	7500 lbs. steam per hour.
(*i*) Amount of water equivalent to 1 in. of gauge-glass at commencing level of test . .	950 lbs. per boiler.
(*j*) Brief resumé of last report of insurance company . .	General condition of boiler very good but fair amount of scale.
(*k*) Condition of the brickwork .	Very bad.
(*l*) Condition of the covering . .	Very bad. Lagging is of an inferior quality and very old.
(*m*) Remarks	The brickwork is generally in a deplorable condition, and the cold-air leakage is enormous.

2. MECHANICAL COAL AND ASH HANDLING.

(*a*) Is the coal handled mechanically?	Yes.
(*b*) If so, state the following particulars :—	
(*b*1) Type of plant . . .	"Boot" elevators to each stoker.
(*b*2) Name of maker . . .	X.
(*b*3) Maker's reference number .	42,619.
(*b*4) When installed . . .	1915.
(*b*5) Number of hours working compared with the boiler plant	Continuously day and night. Stopped at week-ends.
(*b*6) Power required to work the plant	2·85 H.P.
(*b*7) Remarks	Have not had much trouble in working.
(*c*) Is the ash handled mechanically	No.
(*d*) If so, state the following particulars :—	

(*d*1) Type of plant . . .	— — —
(*d*2) Name of maker . . .	— — —
(*d*3) Maker's reference number .	— — —
(*d*4) When installed . . .	— — —
(*d*5) Number of hours working compared with the boiler plant	— — —
(*d*6) Power required to work the plant	1·25 H.P.
(*d*7) Remarks	A spiral screw type of ash elevator was originally installed, but scrapped after two years because of breakdowns. Ashes now taken away by hand in wheelbarrows.

3. GRATES.

(A) Is the firing hand or mechanical	Mechanical.
(B) If hand-fired, state :— . .	Not hand-fired.
(B1) General type of fire-bar .	— — —
(B2) If special make, name of maker	— — —
(B3) If mechanically moved, state power required . .	— — —
(B4) Remarks	— — —
(C) If mechanically fired, state :—	
(C1) Type of stoker (sprinkling, coking overfeed, or coking underfeed) . .	Coking overfeed.
(C2) Name of maker . .	X.
(C3) Maker's reference number .	51,206.
(C4) When installed . . .	With the boilers. One in 1910, two in 1914.
(C5) Amount of power required to drive the stoker mechanism per boiler .	1·25 H.P.
(C6) Remarks	The drive is a small non-condensing steam engine, and the exhaust is blown to atmosphere.
(D) Total grate area on test .	69·00 sq. ft.
(E) Length of bars (including dead plate)	5 ft. 9 ins
(F) Total width of furnace . .	3 ft.

(G) Average air space between the bars	$\frac{1}{4}$ in.
(H) If steam jets are used, state :—	
(H1) Number of nozzles per boiler under front of fires	14.
(H2) Number of nozzles per boiler under back of fires	None.
(H3) Number of nozzles per boiler over the top of the fires .	2.
(H4) Approximate diameter of the nozzles . . .	$\frac{1}{8}$ in.
(H5) Size of steam pipe supplying the nozzles . .	$\frac{3}{4}$ in.
(H6) How is the valve on this steam pipe supplying the nozzles generally worked?	Full open all the time.
(H7) Is there any method in use of determining the amount of steam used by these nozzles . .	None.
(H8) Remarks	No difference is made to the valve controlling the nozzles which is left full open all the time irrespective of the speed of working.
(I) Is the boiler fitted with any smoke preventer or other special type of apparatus auxiliary to the grates?	None.
(J) How are the boiler dampers generally worked? . .	Full open.
(K) Can they be controlled from the firehole?	No.
(L) General remarks . . .	The dampers are worked by weights but the chains are only short and the weights hang over the back of the boilers.

4. CONTROL OF FIRING.

(A) Is the firing controlled by means of flue gas analysis?	No.
(B) If a CO_2 Recorder is used, state :—	

(B1) Is more than one recorder in use?	No.
(B2) Name of maker . . .	X.
(B3) Is it being worked continually? . . .	No, out of order.
(B4) Is it in good condition and giving good results?	No, out of order.
(B5) Remarks	The CO_2 Recorder has not worked for several months, the pen mechanism being out of order.
(C) Is an "Orsat" or other hand apparatus in use? If so, how often?	None in use.
(D) Is there any method of collecting flue gas analysis over a number of hours? If so, give a description . .	None.
(E) Is the plant fitted with draught gauges? If so, state particulars	One draught gauge in fan inlet.
(F) General remarks . . .	No attention is paid to flue gas analysis and draught regulation.

5. ECONOMISERS.

Is the plant fitted with economisers at work?	Yes.
If so, state :—	
(A) Name of maker . . .	X.
(B) Maker's reference No. .	25,625.
(C) When installed . . .	1908.
(D) Number of tubes in the installation	480.
(E) Of what metal are the tubes composed	Cast iron.
(F) Number of tubes at work during the test . .	480.
(G) Height of tubes (or length) .	9 ft.
(H) Total heating surface of the installation	4800 sq. ft.
(I) Number of tubes wide . .	10.
(J) General arrangement . .	Straight line.
(K) Method of driving the scrapers	Small steam engine supplied with economiser.

(L) Conditions as regards scale from the last report of the insurance company . .	Fairly good.
(M) Conditions as regards corrosion	Slight signs of wasting at the bottom.
(N) Is a circulator fitted? If so, state particulars . .	None fitted.
(O) Is cold water (100° or under) ran through the economiser at night or at week-end? .	Yes. Cold water (60°) seems to be run in at week-ends.
(P) Condition of the brickwork	Fairly good.
(Q) Remarks.	The whole economiser seems to be subsiding a little at the chimney end, the ground being bad.

6. CHIMNEY.

(A) Height above firing level . .	Not known exactly, about 150 ft.
(B) Height above ground . .	About 3 ft. more.
(C) Internal dimensions (top) .	6 ft.
(D) Internal dimensions (bottom) .	7 ft. 9 ins. diameter.
(E) Material, brick, stone or steel .	Brick.
(F) Shape, circular, square, horizontal	Circular, square base 12 ft. high.
(G) When was it erected? . .	About 1900.
(H) General condition . . .	Very good.
(I) Is it lined with fire-brick inside? If so, for what height? .	Yes. About one-third the height.
(J) Will it stand cutting for another entrance?	Yes.
(K) Are the foundations good enough for the height to be increased?	Yes.
(L) Remarks	Chimney generally is in fine condition and when built originally was meant for about six boilers.

7. FLUES.

(A) Give a thumb-nail sketch of the general run of the plant .	—— —— ——
(B) What is the internal height of the main flue? . . .	5 ft. 6 ins.
(C) What is the internal width of the main flue? . . .	3 ft.

(D) Do these dimensions hold good from the economiser exit right into the chimney? .	Yes.
(E) Are the flues damp? . .	No.
(F) If "Lancashire" or "Cornish" boilers what is the dimensions of the smallest space in the side flues? . . .	10 ins.
(G) Remarks	The brickwork of the flues is fairly good, but rather leaky, and should be "pointed".

8. MECHANICAL DRAUGHT.

If mechanical draught is in use, is it induced, forced, or "balanced"?	Yes. Induced draught.
State :—	
(A) Name of maker of fan . .	X.
(B) Type of fan (multiple or paddle bladed) . .	Multiple blade.
(C) Maker's reference number .	123.
(D) When installed . . .	1910.
(E) Is fan full housing or not? .	Full housing.
(F) Area of fan inlet . . .	40 ins. diameter.
(G) Area of fan discharge . .	28 sq. ft. (effective).
(H) Diameter of fan runner .	40 ins.
(I) Is the fan provided with ring-lubricated and water-cooled bearings? . .	Two bearings ring-lubricated, one water-cooled.
(J) How is the fan driven? . .	High-speed engine.
(K) If fan driven by steam engine, state :—	
(K1) Length of stroke . .	6 ins.
(K2) Area of piston . .	9 ins. diameter.
(K3) Maximum speed . .	615 R.P.M.
(K4) Is the engine direct-coupled or is it belt-driven . . .	Direct-coupled.
(K5) If direct-coupled, is the fan and engine on combined cast-iron bed-plate? . . .	Yes.
(K6) Is the full boiler pressure on the fan engine or is	

there a reducing valve fitted? If so, what is the steam pressure on the engine stop valve? Is a surplus valve fitted? . . .	Full boiler pressure. No surplus or reducing valve.
(K7) Can the speed be controlled from the fire-hole? . . .	No.
(K8) What is done with exhaust steam from the engine? . . .	Blown away in the air.
(K9) Remarks . . .	Fan discharge not good.
(L) If fan driven by electric motor, state :—	
(L1) Name of maker of motor	— — —
(L2) Maker's reference number	— — —
(L3) Rated maximum revolutions per minute. Output of motor, amps. Output of motor, volts	— — —
(L4) Is the motor direct-coupled or driven (chain, belt or rope)? .	— — —
(L5) If direct-coupled, is the fan and motor on combined cast-iron bedplate? . . .	— — —
(L6) What is the figure of electric current available? amps., volts .	— — —
(L7) Is the current generated on the works or from outside current? .	— — —
(L8) What is the real net price paid for the current? .	— — —
(L9) Can the speed be controlled from the fire-hole? . . .	— — —
(L10) Remarks . . .	— — —
(M) If fan be driven from a line shaft, state :—	

(M1) Method of drive (rope, chain, belt) . .	— — —
(M2) Speed of driving shaft .	— — —
(M3) What are the usual running hours of this shaft? . . .	— — —
(M4) Is there a friction clutch or other arrangement to disconnect the fan at will? . . .	— — —
(N) If any other method driving the fan is adopted, give full particulars . .	No other method.
(O) Normal speed, revolutions per minute at which the fan is run . . .	550 R.P.M.
(P) Maker's maximum rating of the mechanical draught plant	— — —
(P1) Revolutions per minute .	615 R.P.M.
(P2) Cubic feet of gas or air handled at stated temperature (350° F.) per minute . . .	23,000.
(P3) B.H.P. taken at this maximum rating . .	23.
(P4) Remarks . . .	— — —
(Q) Is the draught given sufficient	Not quite.
(R) General remarks . . .	The fan as installed is hardly big enough and seems to be throttled by a bad discharge to the chimney.

9. BOILER FEED-WATER.

(A) What is the source of the feed-water?	River.
(B) If more than one source is used, state the usual proportions .	No other source.
(C) Is the water muddy? If so, is any filtering plant used? and give description . .	Not particularly. No filtering plant used.
(D) Is there any scale? . .	Yes.
(E) Is there any corrosion? .	A little.

(F) Is any chemical or boiler composition used? If so, give :—	None.
(F1) Name of composition .	— — —
(F2) Name of maker . . .	— — —
(F3) How it is added to the boiler?	— — —
(F4) Does it give satisfactory results?	— — —
(F5) Remarks	A boiler composition was used before the water-softening plant was installed.
(G) If any type of water-softening plant is in use, state :— .	Yes.
(G1) Name of maker . .	X.
(G2) Maker's reference number	2578
(G3) When installed . . .	1910
(G4) Maker's rated output of softened water, gallons per hour . . .	2000 gallons.
(G5) How many hours settling does the plant allow of?	2 hours.
(G6) At what output is the plant being worked? . .	About 1500.
(G7) If lime is used, is it as lime cream or milk of lime? .	Lime cream.
(G8) How many times a day is the water analysed? .	Once.
(G9) What is average figure for the analysis before treatment?	21° total hardness.
(G10) What is average figure for the analysis after treatment? . . .	8°.
(G11) Remarks	Softening plant is not being particularly well looked after.
(H) Is any special method adopted for the prevention of corrosion?	No.
(I) Is a trace of alkali in the steam prejudicial to the use of the steam?	No.

10. METHOD OF BOILER FEEDING.

(A) If an injector is used, state :—	
(A1) Is it in regular use or only as a stand-by?	Only as a stand-by.
(A2) Is it live steam, exhaust steam, or mixed pressure?	Live steam.
(A3) Name of maker	X.
(A4) Remarks	Practically never used.
(B) If a boiler feed pump is used, state :—	
(B1) Type of pump	Vertical direct-acting.
(B2) Name of maker	X.
(B3) Maker's reference number	26,727
(B4) When installed	1910.
(B5) Maker's rated duty, amount of water pumped under given conditions of power or steam supply, speed, and boiler pressure	1500 gallons at 12 double strokes per minute with and against 150 lbs. gauge.
(B6) Amount of suction lift to the pump	None falls from overhead tank.
(B7) Average speed of pump	About 15 double strokes per minute.
(B8) If steam driven, what is done with the exhaust steam?	Blows away in the air.
(B9) Average steam or power taken by the pump	Approximately 150 lbs. steam per hour.
(B10) Remarks	Feed pump gives no trouble at all.
(C) If feed-water regulators are in use, state :—	
(C1) Number of regulators at work	3.
(C2) Name of maker	X.
(C3) When installed	1914.
(C4) Remarks	Do not work particularly well.
(D) General remarks	— — —

11. MEASUREMENT OF BOILER FEED-WATER.

(A) Is there any method in use of measuring continuously the

amount of feed-water pumped to the boilers? . . .	No.
(B) If tanks are used give a description	— — —
(C) If a water meter is used, state.—	
(C1) Name of maker . . .	— — —
(C2) Maker's reference number .	— — —
(C3) When installed . . .	— — —
(C4) Is it used regularly? . .	— — —
(C5) Is there any test tank or other method in use for testing its accuracy? .	— — —
(D) General remarks . . .	Staff have no idea of the amount of water evaporated.

12. SUPERHEATERS.

If the plant is fitted with superheaters, state:—	
(A) Number of boilers fitted .	3.
(B) Number used on test . .	2.
(C) Name of maker . . .	X.
(D) Maker's reference number .	26,200
(E) When installed . . .	With the boiler; one 1910, two 1914.
(F) Can the superheat be controlled with dampers? .	No.
(G) Is the superheat fitted with bye-pass to main steam circuit?	No.
(H) Number of tubes per superheater	36.
(I) Heating surface of tubes per superheater	176 sq. ft.
(J) What is the maker's rated output, temperature rise per stated evaporation of the boilers at stated pressure?	100° F., superheat.
(K) Is provision made for further tubes to be added if necessary to the existing superheater header? . .	No.
(L) General remarks . . .	Superheaters have given no trouble.

13. MEASUREMENT OF STEAM OUTPUT.

Is there any steam meter installed to measure the actual steam output of the plant?	None.
If so, state :—	
(A) How many steam meters installed? . . .	— — —
(B) At what points are they installed?	— — —
(C) Name of maker . . .	— — —
(D) Maker's reference number .	— — —
(E) General remarks . . .	They seem to be impressed with the idea of installing steam meters.

14. STEAM PRESSURE.

(A) What is the blow-off pressure of the plant? If different boilers have different pressure, give full particulars .	150 lbs. Only one pressure.
(B) What is the lowest pressure permissible on the plant without reducing the factory efficiency, that is, what margin of pressure is permissible? .	140 lbs. 10 lbs. margin.
(C) General remarks . . .	Some low-pressure steam is used through a reducing valve, but is not much, and this mill seems to do very little "boiling".

PARTICULARS RELATING TO THE BURNING OF FUEL.

15. DESCRIPTION AND QUALITY OF FUEL USED.

(A) Nature of fuel . . .	Small slack.
(B) Name of fuel	X.
(C) Price per ton delivered to the firehole or fuel conveyers .	£2 5s. per ton.
(D) What is the average fuel used all the year round? . .	Small slack as above.
(E) Remarks	In general, have not used much other coal.

16. ANALYSIS OF THE FUEL.

(A) Gross B.Th.U. in dry coal per lb., as fired . . . . 12,608.
(B) Net B.Th.U. per lb. corrected for moisture in coal . . 11,715.
(C) Percentage of ash . . . 11·0 per cent.
(D) Percentage of water . . 6·5 per cent.
(E) Remarks . . . . This coal is stated to be about average quality.

17. AMOUNT OF FUEL USED.

(A) Total amount of fuel used on test . . . . . . 15,960 lbs.
(B) Corresponding fuel burnt per boiler per hour . . . 997·5 lbs.
(C) Corresponding fuel burned per sq. ft. grate area per hour . 28·5 lbs.
(D) Is there much difference between one hour and another in the fuel consumption on the test? . . . . Not much.
(E) Is there much difference in fuel consumption on individual boilers? . . . . . No.
(F) Remarks . . . . Load is very steady for a paper mill. Approximate variation in steam demand per half-hour does not exceed 20 per cent.

18. ASH PARTICULARS.

(A) Total amount of ash produced (lbs.) . . . . . . Not taken.
(B) Percentage of unburnt material in ash (by analysis) . . — — —
(C) Corresponding B.Th.U. per lb. — — —
(D) Remarks. . . . . . — — —

19. FLUE GAS TEMPERATURES.

(A) Average temperature leaving boiler . . . . . . 300° F.
(B) Average temperature leaving superheater . . . . 580° F.

(C) Average temperature entering economiser . . .	570° F.
(D) Average temperature leaving economiser	400° F.
(E) Average temperature at chimney base	400° F.
(F) Remarks	No pyrometers are installed permanently on the plant

20. DRAUGHT.

(A) Draught in chimney base or near fan inlet, ins. W.G. .	0·95 in.
(B) Draught at exit (or side flues) of boiler, ins. W.G. . .	0·50 in.
(C) Draught over the boiler fire, ins. W.G.	0·20 in.
(D) If forced draught, pressure over fire, ins. W.G. . .	No forced draught.
(E) If forced draught, pressure in ash-pit, ins. W.G. . .	No forced draught.
(F) Remarks	As already stated, fan not big enough, and badly installed.

21. FLUE GAS ANALYSIS.

(A) Complete analysis.	
(A1) Percentage of CO_2 . .	5·8 per cent.
(A2) Percentage of oxygen .	14·5 per cent.
(A3) Percentage of CO . .	0·2 per cent.
(A4) Percentage of nitrogen (by difference)	79·5 per cent.
(A5) Average of how many analyses . . .	Six different samples of about 15,000 c.c. each.
(A6) Remarks	— — —
(B) Combustion recorder figures .	— — —
(B1) Percentage of CO_2 . .	6·00 per cent.
(B2) Average of how many analyses . . .	About 150.
(B3) How many hours run .	8·00 hours.
(B4) Remarks	As already noted there is a lot of leakage of cold air.

22. BLACK SMOKE.

Is the plant troubled with black smoke	No. Very good on the whole.

PARTICULARS RELATING TO THE PRODUCTION OF STEAM.

23. AMOUNT OF WATER EVAPORATED.

(A) Method of measuring the water on the test	Calibrated pressure meter.
(B) Total net amount of water evaporated on the test (lbs.)	105,328 lbs.
(C) Corresponding water evaporated per boiler per hour (lbs.) .	6583 lbs.
(D) Corresponding water evaporated per sq. ft. grate area per hour (lbs.)	190·8 lbs.
(E) Remarks	The variation in demand per half-hour is less than usual for a paper mill (see test log figures).

24. TEMPERATURE OF FEED-WATER.

(A) Average temperature before economisers . . .	121° F.
(B) Average temperature after economisers . . .	296° F.
(C) Corresponding percentage of coal bill saved by economisers	16·1 per cent.
(D) Remarks	The economiser is doing extremely well.

25. STEAM PRESSURE.

(A) Average lbs. per sq. in., gauge	147 lbs.
(B) If different pressures on the same plant, give the separate averages for each division of boilers	Only one pressure.
(C) Average lbs. per sq. in., absolute	162 lbs.
(D) Remarks	Steam pressure is maintained on the whole very well.

26. SUPERHEAT.

(A) Temperature of saturation of steam at the average pressure of the plant . . .	364·2° F.

(B) Average temperature of superheated steam leaving the superheaters on boilers fitted with superheaters . . .	475° F. All fitted.
(C) Average temperature of superheated steam leaving the plant (boilers fitted and not fitted with superheaters both included)	475° F. All fitted.
(D) Corresponding average degrees of superheat	475° F.
(E) In general is each individual superheater giving the same amount of rise? . . .	Yes.
(F) Percentage saving in the coal bill due to superheaters .	5·1 per cent.
(G) Remarks.	Superheater installation in general working very well.

27. AUXILIARY STEAM OR POWER USED FOR THE PRODUCTION OF STEAM.

(A) Mechanical coal handling .	0·4 per cent.
(B) Mechanical ash handling .	0·3 per cent.
(C) Mechanical stoker or hand-fired, mechanical moving furnace drive	0·5 per cent.
(D) Steam jets	8·05 per cent.
(E) Mechanical draught . . .	2·4 per cent.
(F) Boiler feed pump . . .	0·9 per cent.
(G) Injector	None.
(H) Water softening . . .	0·2 per cent.
(I) Economiser scrapers . .	0·2 per cent.
(J) Any other auxiliary steam .	None.
Total	12·95 per cent.
(K) Remarks	Enormous amount of steam being taken by the steam jets.

TABULATED RESULTS.

31. Water evaporated per lb. fuel, as fired	6·60 lbs.
32. Equivalent evaporation of water from and at 212° F. per lb. fuel, as fired	7·52 lbs.
33. Equivalent evaporation of water from and at 212° F., evaporated per 1,000,000 B.Th.U. in fuel, as fired	641·9 lbs.

34. EFFICIENCY OF PLANT.

(A) Net working thermal efficiency of the plant after deducting the steam or power used auxiliary to the production of steam corresponding to 12·95 per cent. of the total steam production of the plant	57·20 per cent.
(B) Percentage of total heat absorbed by the boiler . .	52·31 per cent.
(C) Percentage of total heat absorbed by the economiser .	10·02 per cent.
(D) Percentage of total heat absorbed by the superheater .	3·37 per cent.

35. COST IN FUEL FOR THE EVAPORATION OF 10,000 LBS. WATER . . . 365·3 pence.

36. LONG CHECK TEST

(A) Duration (hours) . . .	165·00 hours.
(B) Dates and times . . .	— — —
(C) Quality of fuel used . .	Small slack.
(D) Price of fuel used . . .	£2 5s. per ton.
(E) Amount of fuel used, tons .	110·58.
(F) Analysis of fuel used :—	
(F1) B.Th.U. (net calculated) .	11,900.
(F2) Ash	11½ per cent.
(G) Total net amount of water evaporated	162,040 lbs.

(H) Approximate average temperature of inlet water . .	120° F.
(I) Water evaporated per lb. coal .	6·54 lbs.
(J) Cost in fuel to evaporate 1000 gallons of water . . .	368·6 pence.
(K) Approximate annual coal bill of the plant	£12,450.
(L) Remarks. . . .	Week's results would be expected to be like the day's test since the plant works day and night.

SUMMARY.

In summing up, the whole question of boiler plant testing I should like to emphasise again that the first necessity of any International Code is that it must be practical, consistent with reasonable accuracy, so that testing of boiler plant can be carried out regularly all the year round.

Such a code in my opinion should include the following, as already discussed in detail :—

1. The separation of boiler plant testing from every other form of testing, especially that of steam engines.

2. The duration of the test to be 8·0 hours, and longer if possible, six hours to be allowed if peculiar local conditions demand it, but no test to be less than this.

3. In every case a long check test of one week (168 hours) or longer, to be essential, so as to include night and week-end performances.

4. The dried fuel to be analysed in a bomb calorimeter and a calculated heat value be taken based on the percentage of water and taking the temperature of the boiler plant exit gases as 212° F. The determination of hydrogen, with the corresponding calculated lower heat value, to be abandoned.

5. The use of a CO_2 Recorder for the whole duration of the trial to be regarded as essential.

6. The gases to be analysed for CO and unburnt gases, either by the use of the "Duplex Mono" or by taking automatically a very large sample, say 20,000 c.c. at the rate of at least 2000 c.c. per hour, and analysing this sample with the "Orsat" or other hand apparatus.

7. In measuring the boiler feed-water approved makes of water meter be allowed, provided they are fitted with a calibrated test tank, or tested before and after the trial.

8. The determination of the moisture in the steam be abandoned until reliable methods are discovered.

9. The specific heat of superheated steam be taken according to Knoblauch and Jakob's work and the figure of 0·48 be disregarded.

10. All the steam used auxiliary to the production of steam must be determined with great care, and deducted in calculating the efficiency. In the case of steam jets, either a steam meter or some form of surface condenser to be used.

11. The new figure of "lbs. of water from and at 212° F. per 1,000,000 B.Th.U." be included in the test figures.

12. The method of calculating the results shall be essentially from the heat of the fuel, and not by the "heat balance sheet" method based on the flue gas analysis.

The general testing methods in vogue in the world to-day are academic and unpractical, although very few tests indeed can ever have been carried out according to the "Civils" Code.

Certainly most of the boiler plants of Great Britain are small, say two or three "Lancashire" boilers, yet an International Code must be applicable to all plants, no matter how large, and the larger the plant the more urgent is the necessity for continual testing. The impossibility of the "Civils" Code methods is best represented by taking an average fairly large-sized factory boiler plant, of, say, ten "Lancashire" boilers burning 10,000 tons of coal per annum, with a fairly complete array of accessories in the way of economisers and mechanical stokers, but without superheaters, and with two different, high and low, boiler pressures.

In the first place, the instructions are to insert steam driers in the steam pipe circuit of the plant, and then to determine the moisture in the steam. This means on the given plant, with, say, two 8-in. steam mains, high pressure and low pressure, that the whole factory must be shut off, whilst two lengths of the main steam pipes are taken down and two 8-in.

steam driers fixed in the circuits, with special "making-up" pieces, a formidable job itself. Huge water tanks to measure the feed-water have to be carted in, and in most cases the greater part of the boiler feed pipe circuit will have to be dismantled to fit in the tanks. If we are to assume that definite instructions are given to determine the amount of steam used by the 150 or so steam nozzles of the mechanical stokers, then either apparently all the small steam pipes supplying these stokers are to be dismantled and a fresh steam pipe circuit connected up to one of the boilers, which has to be tested separately, and the evaporation measured, or else each of the nozzles must be measured for area and a crude empirical formulæ used. That is to say, there are really two boiler tests, which means a separate smaller set of water measuring tanks. In addition to this, samples of flue gas have to be taken in small tubes filled with mercury, and a continual series of CO_2 analysis carried out by "Orsat" apparatus, and at the beginning and end of the trial every one of the twenty fires has to be measured for thickness by means of the "tools" already discussed. Then there is a complete chemical analysis of various samples of coal to be carried out, that is, the determination of the carbon, oxygen, hydrogen, etc., in addition to the heating value by means of a bomb calorimeter.

Such a test would dislocate the usual working of the boiler plant for at least a month, and on the actual test at least a dozen trained observers would be required, whilst, as an anti-climax, three hours is sufficient for the test! It is therefore not to be wondered at that boiler tests are not carried out according to the "Civils" Code, and that boiler testing is not popular when such methods are regarded as necessary.

It should be the endeavour of an International Code to avoid such mistakes. We have got to remember that there must always be a considerable margin of error. Thus the coal and water, whether by mechanical or laborious hand means, cannot be weighed to within 1 per cent. of absolute accuracy, and certainly the percentage of CO_2 cannot be

determined to within $\frac{1}{2}$ per cent., if only because of the difficulty of obtaining a true average sample. It is therefore no use going to a lot of trouble over points that are of no practical importance, and what is necessary is to concentrate particularly on the points that matter, such as the weight of the water evaporated, the weight of the coal used, the proper sampling and analysis of the fuel, and the auxiliary steam or power.

I am sure that the combined experience of American, British and French engineers, who have had actual practical experience of boiler plant testing would soon formulate a practical and accurate International Code which would be of immense benefit to the engineering profession in all the countries concerned, and if this book is a help towards such a deserving object its success will have been achieved.

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